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EVALUATIONS OF PRESERVATIVE ENGINE OIL CONTAINING VAPOR-PHASE CORROSION INHIBITOR AND A SIMPLIFIED ENGINE PRESERVATION TECHNIQUE

INTERIM REPORT
BFLRF No. 269

By

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Under Contract to

U.S. Army Belvoir Research, Development
and Engineering Center
Materials, Fuels and Lubricants Laboratory
Fort Belvoir, Virginia

Contract No. DAAK70-87-C-0043

December 1990

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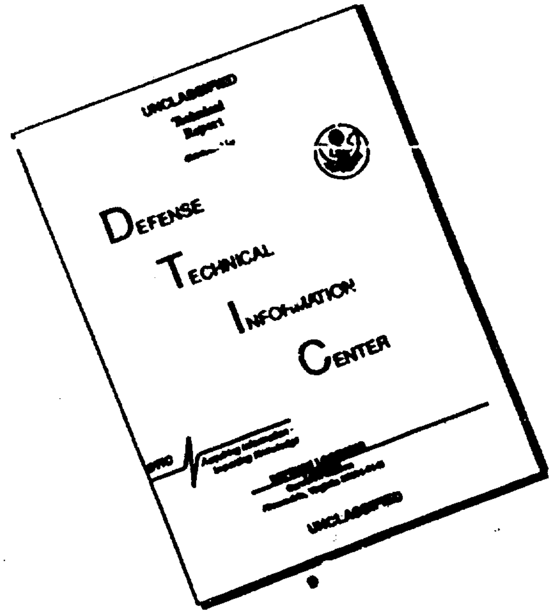

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY N/A	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Interim Report BFLRF No. 269	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Belvoir Fuels and Lubricants Research Facility (SwRI) 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Southwest Research Institute 6220 Culebra Road San Antonio, Texas 78228-0510	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Belvoir Research, Development and Engineering Center 8b. OFFICE SYMBOL (If applicable) STRBE-VF	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK70-85-C-0007; WD 17 DAAK70-87-C-0043; WD 3 and 8
8c. ADDRESS (City, State, and ZIP Code) Fort Belvoir, VA 22060-5606	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62786 / PROJECT NO. 1L762786 AH20 / TASK NO. 123 / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Evaluations of Preservative Engine Oil Containing Vapor-Phase Corrosion Inhibitor and a Simplified Engine Preservation Technique (U)

12. PERSONAL AUTHOR(S)

Frame, Edwin A.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM July 85 TO Sept 90	1990 December	161

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Preservative Engine Oil MIL-L-21260 Engine Preservation MIL-E-10062E Vapor-Phase Corrosion

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The objectives of this project were: (1) to determine the feasibility of adding a vapor-phase corrosion inhibitor (VCI) component to improve the preservation performance of MIL-L-21260 and (2) to evaluate a less complicated engine preservation procedure.

A simultaneous two-phase approach was conducted. Phase 1 involved the formulation and evaluation of experimental VCI oils, while Phase 2 was the evaluation of a simplified engine preservation procedure. VCI oil formulation was conducted by Ronco Laboratory under subcontract. Compatibility of the experimental VCI oils with metal coupons, elastomers, and fuel filters was determined. Effectiveness of the experimental VCI oil was evaluated in a 3-year outdoor engine storage test. The engines were preserved using an experimental, simplified preservation procedure.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. T. C. Bowen	22b. TELEPHONE (Include Area Code) (703) 664-3576	22c. OFFICE SYMBOL STRBE-VF

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. ABSTRACT

The simplified engine preservation procedure proved to be acceptable as engines stored for 3 years in a very severe environment were judged to have been adequately preserved. Engine oil meeting specification MIL-L-21260 provided satisfactory protection during the 3-year storage test. The experimental VCI oil also provided satisfactory storage protection during this test; however, there was no observable advantage for the VCI oil The VCI oil had acceptable compatibility with an elastomeric flex ring, metal coupons (except lead), and fuel filters.

EXECUTIVE SUMMARY

Problems and Objectives: Current military engine preservation practices involve use of preservative/operational engine oil meeting military specification MIL-L-21260. Engines are preserved in accordance with MIL-E-10062E. This preservation technique is a costly, complex, and man power-intensive operation. The objectives of this project were: (1) to determine the feasibility of adding a vapor-phase corrosion inhibitor (VCI) component to improve the preservation performance of MIL-L-21260 and (2) to evaluate a less complicated engine preservation procedure.

Importance of Project: It was estimated that the current MIL-E-10062E engine preservation procedure requires approximately 200 percent more time than a simplified, candidate procedure. If the candidate procedure is successful, then substantial reductions in man-hour costs of engine preservation are possible. In addition, if an appropriate VCI component can be incorporated in MIL-L-21260 oil, improved engine corrosion protection could be realized. As preservative engine oil drains off surfaces with time, the corrosion protection can be continued with the VCI component.

Technical Approach: A simultaneous two-phase approach was conducted. Phase 1 involved the formulation and evaluation of experimental VCI oils, while Phase 2 was the evaluation of a simplified engine preservation procedure. VCI oil formulation was conducted by Ronco Laboratory under subcontract. Compatibility of the experimental VCI oils with metal coupons, elastomers, and fuel filters was determined. Effectiveness of the experimental VCI oil was evaluated in a 3-year outdoor engine storage test. The engines were preserved using an experimental, simplified preservation procedure.

Accomplishments: The simplified engine preservation procedure proved to be acceptable as engines stored for 3 years in a very severe environment were judged to have been adequately preserved. Engine oil meeting specification MIL-L-21260 provided satisfactory protection during the 3-year storage test. The experimental VCI oil also provided satisfactory storage protection during this test; however, there was no observable advantage for the VCI oil. The VCI oil had acceptable compatibility with an elastomeric flex ring, metal coupons (except lead and copper containing panels), and fuel filters.

Military Impact: The VCI oil provided no advantage in preservation over the MIL-L-21260 oil. The simplified preservation procedure was successful and would significantly impact the military by reducing the time and cost for engine preservation. Adoption of this procedure would contribute to improve equipment readiness as no downtime would be required for partial engine disassembly as in the current practice.

FOREWORD/ACKNOWLEDGMENTS

This work was conducted at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute (SwRI) under Contract Nos. DAAK70-85-C-0007 and DAAK70-87-C-0043 during the period July 1985 through September 1990. The work was funded by the U.S. Army Belvoir Research, Development and Engineering Center (Belvoir RDE Center), Ft. Belvoir, Virginia 22060-5606, with Messrs. F.W. Schaekel and T.C. Bowen (STRBE-VF) serving as the contracting officer's representatives and Mr. R. Thiesfeld and then Mr. Bowen (STRBE-VF), as the project technical monitors.

In addition to Messrs. Schaekel, Bowen, and Thiesfeld of Belvoir RDE Center, the following people are acknowledged for their contributions to this project: Messrs. Don Wells, Leonel Farias, Raphael Leal of Corpus Christi Army Depot (CCAD); Mr. Joe Bristoe of Red River Army Depot; Mr. W.E. Butler, Jr., BFLRF, for coordinating the engine storage and making the quarterly inspections at CCAD; Mr. K.E. Hinton, BFLRF, for his attention to detail in conducting the materials compatibility investigations; Messrs. S.R. Westbrook and G.B. Bessee, BFLRF, for their conduct of filter plugging tests; and Mr. Tony Barajas of SwRI for cooperation in supplying, rebuilding and preserving the 6V-53T engines.

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I. INTRODUCTION/BACKGROUND

The U.S. Army has unique requirements for engine preservation. While commercial engine producers usually do not routinely store an engine for more than 6 months, the Army often requires storage of engines for extended periods of time. In addition, the Army must maintain the stored equipment in a readiness posture; thus, the need arises for a preservative engine oil that can also be used operationally. It was postulated that performance of preservative/operational oil MIL-L-21260 (1)* could be improved by incorporating vapor-phase corrosion inhibition (VCI) technology. This project investigated the feasibility of producing an improved preservative/operational engine oil with VCI properties.

In addition, this project addressed the need for a simplified engine preservation procedure. Military engines are prepared for storage following Specification MIL-E-10062E, "Engine, Preparation for Shipment and Storage Of."(2) Engine preservation following MIL-E-10062E is a complex, time-intensive operation that requires partial disassembly of the engine. In a related program, Belvoir RDE Center Packaging, Development and Engineering group contracted with Radian, Inc. to investigate commercial engine preservation materials and techniques as alternatives to existing military specifications and standard procedures.(3) An evaluation of a simplified engine preservation technique was conducted during this project in conjunction with the evaluation of an experimental engine preservative/operational oil that contains VCI.

II. OBJECTIVES

The objectives of this project were (1) to determine the feasibility of adding a vapor-phase corrosion inhibitor (VCI) component to preservative/engine oil MIL-L-21260, and (2) to evaluate a less complicated and more efficient engine preservation procedure.

* Underscored numbers in parentheses refer to the list of references at the end of this report.

III. APPROACH

The approach included two separate efforts. One effort was to evaluate available VCI preservation materials and develop an experimental preservation engine oil (PEO) that contained VCI. Experimental oil formulation was conducted by Ronco Laboratories, Pittsburgh, PA. BFLRF evaluated the effectiveness of the experimental Ronco VCI oil in the following areas:

- 3-year outdoor exposure storage tests of diesel engines were conducted in a severe Gulf of Mexico coastal environment.

- Compatibility of PEO + VCI with Stanadyne Fuel Injection Pump polyurethane flex rings, metal coupons, fuel filters and elastomers was determined.

The second effort was to assess various engine preservation techniques and to recommend a simplified procedure for evaluation. A contract with Radian was established and monitored by Belvoir RDE Center Packaging, Development and Engineering group.(3) Radian contacted numerous companies involved in engine preservation to determine their practices. A simplified engine preservation technique was identified for evaluation by BFLRF.

IV. DISCUSSION OF RESULTS

A. Engine Preservation Procedures

U.S. Army engines are preserved following military Specification MIL-E-10062 preservation procedure.(2) The procedure is complex and labor intensive as illustrated in the following summary of MIL-E-10062 prepared by Radian (3):

> "New equipment shall have engine crankcases drained of existing lubricating oil. The drain plug shall be replaced. The engine crankcase shall be filled to the operating level with the correct grade (weight) of preservative lubricating oil conforming to MIL-L-21260 specification.

"The fuel intake line shall be disconnected at an accessible point. A portable container with two compartments shall be connected to the fuel intake line. One compartment shall contain fuel conforming to VV-F-800, and the other shall contain Type P-10, Grade 10 preservative oil (MIL-L-21260). The fuel injector return line shall be disconnected at an accessible point and arranged for drainage into a recovery container. Engine shall be started and operated at fast idle until thoroughly warm. The engine shall be accelerated to 3/4 speed, at which time the fuel supply shall be switched to portable container containing Type P-10 preservative oil. Engine shall be operated at this speed until undiluted preservative oil is flowing out of fuel injector return line into recovery container. Engine shall be stopped and allowed to cool to either 100°F or to the ambient temperature, if the ambient temperature is greater than 100°F. The intake manifold, exhaust manifold, and valve rocker covers shall be removed. Each intake valve shall be manually depressed, and one-fourth of the predetermined amount of MIL-L-21260 preservative oil shown in Section 3.8 of MIL-E-10062 shall be atomized sprayed past each open inlet valve into the cylinder. Repeat this procedure on the exhaust valve side by depressing each exhaust valve and atomize spray one-fourth of the predetermined amount of MIL-L-21260 preservative oil past each open exhaust valve into the cylinder. Slowly turn over the engine, preventing ignition, one revolution, to spread the preservative oil over the cylinder walls. Repeat the process of depressing each inlet and exhaust valve, and atomize spray one-fourth the amount of preservative oil past each open intake and exhaust valve. Spray exposed valve actuation gear with preservative oil. Reinstall intake manifold, exhaust manifold, and valve rocker cover. *Seal all openings into* engine, and tag engine as being preserved."

Radian identified, analyzed, and summarized five preservation methodologies. Radian found that MIL-E-10062 procedure, while providing the maximum corrosion protection, requires approximately 170 percent more time to perform than the next most involved procedure and 530 percent more time than the simplest procedure. A simple and effective alternative procedure was identified that comes closest to providing the protection of MIL-E-10062. A summary of this alternate procedure as prepared by Radian follows (3):

Simplified Candidate Engine Preservation Procedure

"New equipment shall have engine crankcases drained of existing lubricating oil. The drain plug shall be replaced. The engine crankcase shall be filled to the operating level with the correct grade (weight) of preservative lubricating oil conforming to MIL-L-21260 specification.

"The fuel intake line shall be disconnected at an accessible point. A portable container with two compartments shall be connected to the fuel intake line. One compartment shall contain fuel conforming to VV-F-800 and the other shall contain Type P-10, preservative oil (MIL-L-21260). The fuel injector return line shall be disconnected at an accessible point and arranged for drainage into a recovery container. The air inlet shall be disconnected at the point nearest the intake manifold or turbo, as applicable. Engine shall be started and operated at fast idle **until thoroughly warm**. The engine shall be accelerated to 3/4 speed, at which time the fuel supply shall be switched to portable container containing Type P-10 preservative oil. The engine shall be operated at this speed until the undiluted preservative oil is flowing out of the fuel injector return line into the recovery container. Two minutes prior to engine shutoff, begin atomize-spraying oil conforming to the crankcase grade of MIL-L-21260 specification preservation oil in through the open intake manifold. After 2 minutes of operation, shut off the engine. When the engine has completely stopped, turn off the atomize spray of oil directed into the intake manifold. When the engine has cooled to an acceptable temperature, seal all openings with waterproof tape. Tag the engine as having been preserved."

This procedure of spraying preservative oil into the air intakes while the engine is running is used by the Industrial Engines Operations of the Ford Motor Company, by Teledyne Wisconsin Motors in their commercial engines, and was recommended by the Mobil Oil Company. Ford Motor Company has used this procedure to preserve engines for 4 years of storage with no corrosion problems. The candidate engine preservation procedure was evaluated during this project in conjunction with determining the effectiveness of experimental PEO + VCI.

B. Oil Formulation by Ronco Laboratories

SwRI/BFLRF requested quotations from several sources for a fixed-price contract research effort to develop and supply three drums of three different PEO + VCI oils. The experimental oils were to be based on addition of VCI agent to a given qualified MIL-L-21260 product and were to pass all the specification bench tests of MIL-L-21260. OEM Industrial Corporation/Ronco Laboratories, Pittsburgh, PA, was low-bidder, and was awarded the contract. Their efforts are documented in Reference 4, which is included as Appendix A.

Ronco supplied three drums of experimental VCI/Preservative engine oils. Laboratory inspections and blend composition for the three Ronco oils and the neat MIL-L-21260 oils (PEO-30, AL-14777/AL-15435-L, and PEO-10, AL-15344-L) are presented in TABLE 1.

The SAE-10 grade of PEO + 0.5 percent VCI-B was to be used to fuel the engines during preservation. Because VCI-A, amine salt additive, had caused field problems with fuel injection pumps, Ronco elected to supply a revised formulation based on additive VCI-B (Vaden 500). Properties of VCI-B additive are presented in TABLE 2. This additive is a nitrogen-containing, highly basic material. Fig. 1 is an infrared trace of VCI-B and is consistent with the presence of amine material.

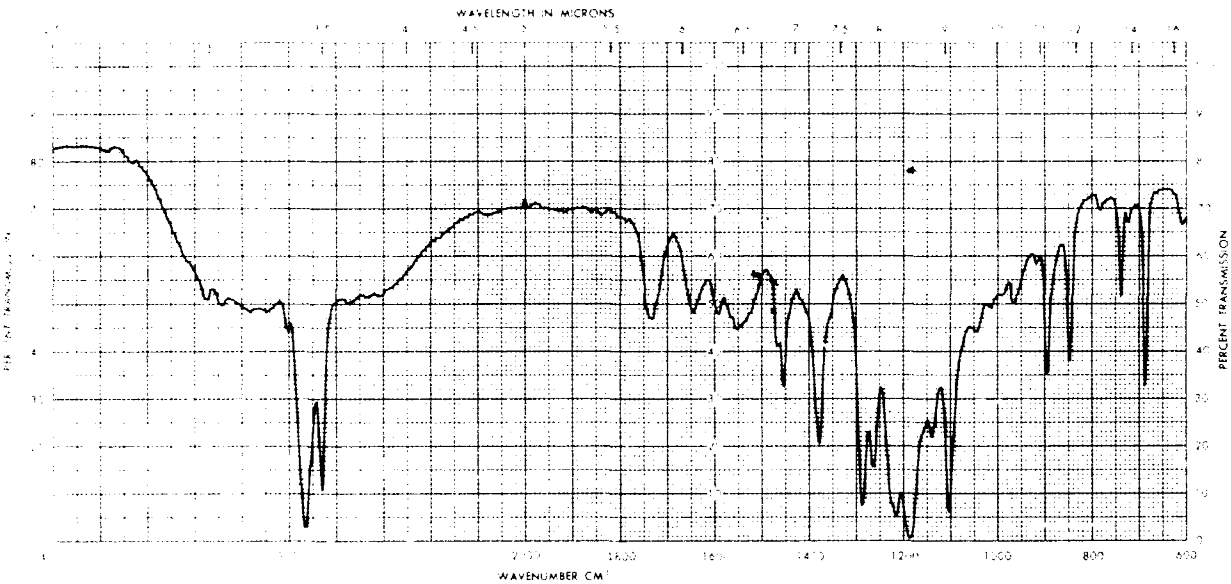

Figure 1. <u>Infrared trace of VCI-B</u>

Analyses of the revised formulation, AL-15434-L, which contained PEO-30 + 0.5 percent VCI-B are presented in TABLE 1, along with limited analyses of PEO-10 + 0.5 percent VCI-B (AL-15437). Neat PEO (AL 14777) passed the Corrosion Protection, Humidity Cabinet, 30-day test (FTM-791 Method 5329.2), while PEO + 0.5 percent VCI-B failed the test. Engine preservation was conducted using experimental PEO + 0.5 percent VCI-B.

TABLE 1. Preservative Oil Properties

AL-Code No. (AL- -L)	14777/15435	15344	15291	15292	15293	15434	15437
%M MIL-L-21260, Grade 30	100	--	99.7	99.5	99.3	89.5	--
%M MIL-L-21260, Grade 10	--	100	--	--	--	--	99.5
%M VCI-A	--	--	0.3	0.5	0.7	--	--
%M VCI-B	--	--	--	--	--	0.5	0.5
K. Vis, at 40°C, cSt	90.31	36.84	93.62	95.63	97.17	92.78	36.25
K. Vis, at 100°C, cSt	10.79	6.15	10.63	10.75	11.13	10.78	6.04
VI	103	114	96	95	99	100	112
TAN	1.9	1.9	2.0	2.1	2.8	3.6	3.2
TBN (D 664)	3.1	4.1	3.5	3.9	5.0	3.0	4.2
N, %	0.039	0.044	0.058	0.067	0.073	0.058	0.051
S, %	0.72	0.91	0.63	0.62	0.63	0.73	ND*
Sulfated Ash, %	0.85	0.73	0.84	0.83	0.81	0.87	ND
GCBP Distribution, °C at wt% off							
1	335	326	335	328	324	336	ND
5	391	354	398	397	396	401	ND
10	412	367	418	417	417	420	ND
20	431	386	436	435	436	439	ND
30	445	401	449	449	449	454	ND
40	457	416	462	461	462	468	ND
50	471	431	475	475	476	483	ND
60	485	446	490	489	490	501	ND
70	502	464	508	508	508	526	ND
80	526	486	537	535	536	600	ND
90	>600	524	>600	>600	>600	>600	ND
Residue, wt%, 600°C	10.7	5.9	12.6	12.3	12.0	20.0	ND

TABLE 1. Preservative Oil Properties (Cont'd)

AL-Code No. (AL- -L)	14777/15435	15344	15291	15292	15293	15434	15437
%M MIL-L-21260, Grade 30	100	--	99.7	99.5	99.3	89.5	--
%M MIL-L-21260, Grade 10	--	100	--	--	--	--	99.5
%M VCI-A	--	--	0.3	0.5	0.7	--	--
%M VCI-B	--	--	--	--	--	0.5	0.5
Elements, ppm by ICP							
Ca	660	409	500	500	500	659	ND
Ba	3	1	5	4	4	5	ND
Mg	360	380	413	422	419	426	ND
Zn	1454	1560	1548	1596	1590	1545	ND
P	972	896	917	964	934	929	ND
B	<1	<1	1	1	1	1	ND
Si	4	6	5	5	5	2	ND
Cu	<1	<1	<1	<1	<1	<1	ND
Na	512	630	750	740	800	710	ND

ND = Not Determined.

TABLE 2. Properties of VCI-B

Property	Method	Value
K. Vis at 40°C, cSt	D 445	34.9
Flash Point, °C	D 92	77
TAN	D 664	8
TBN	D 664	125.7
N, %	D 4629	3.37
Elements, %	XRF	
S		<0.01
Ca		NIL
Ba		NIL
Zn		NIL
P		NIL
Elements, ppm	ICP	
Ba		19
B		16
Mg		1
Mn		<1
Mo		1
Ni		<1
P		16
Zn		44
Ca		2
Cu		<1
Na		278

C. Oil Formulation by BFLRF

BFLRF has conducted a literature search and prepared a data base report (5) covering volatile corrosion inhibitor composition. As a follow on to this work, BFLRF conducted a limited investigation of the effectiveness of commercially available VCI additives. One of the procedures used to evaluate the effectiveness of VCI additives was to blend the additive in a MIL-L-21260 oil and run the Vapor Phase Protection (VPP) test found in Section 4.10.2 of MIL-P-46002, Preservation Oil, Contact and Volatile Corrosion-Inhibited. (6) The corrosion test is conducted using SAE 1009 steel coupons.

The first VCI additive investigated was coded "additive VCI-V." Blends of additive VCI-V at 1, 3, and 5 vol% were made in MIL-L-21260 SAE-30 grade oil (AL-14777). Oil AL-14778 is a MIL-P-46002-qualified product and was included in the VPP test for reference information. TABLE 3 shows the complete physical and chemical inspection properties for the MIL-L-21260 SAE-30 grade oil, the MIL-P-46002 product, and blend 115A (5 vol% VCI-V). Additive VCI-V contributed barium and nitrogen to the finished oil and raised the total base number. TABLE 4 shows the blend composition and test results for the Humidity Cabinet and Vapor Phase Protection (VPP) tests. All oils evaluated passed the 30-day Humidity Cabinet test. Test panels from the VPP test are shown in Fig. 2. In the VPP test, MIL-P-46002 oil passed the grade 1 conditions, while oil blend 115A (5 vol% VCI-V) was a borderline (BL) fail. All other oils failed the grade 1 conditions. Tested at grade 2 conditions, the MIL-L-21260 oil still failed; however, Oil 115A (5 vol% VCI-V) passed, and Oil 115B (3 vol% VCI-V) was a borderline (BL) pass.

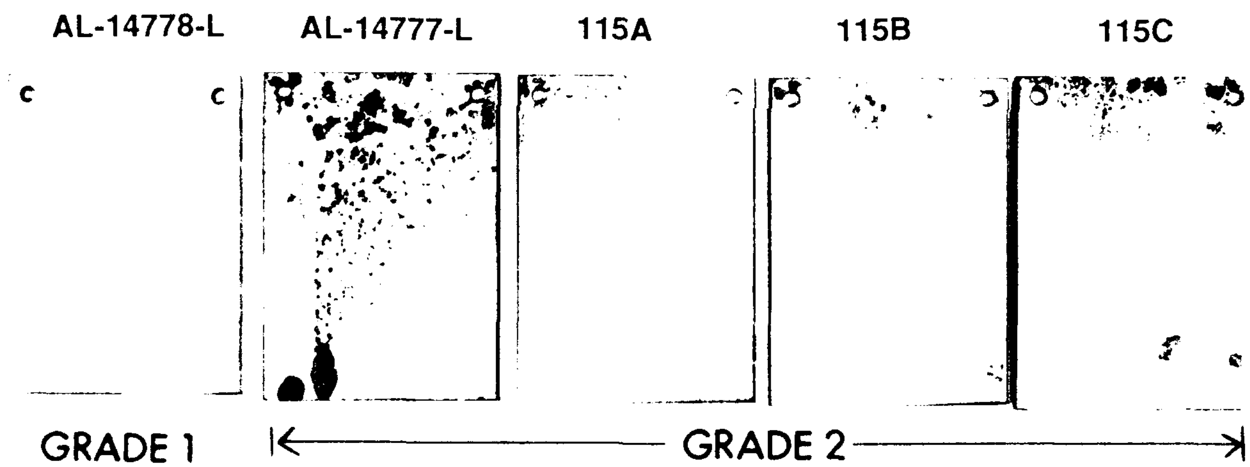

Figure 2. VPP test results

An analytical technique based on differential infrared analysis has been developed to monitor the VCI-V content of an oil blend. Net absorbance of the peak at 1050 cm^{-1} shows linear response to inhibitor content to a detection limit of 0.2 percent. The standard curve is presented in Fig. 3. This technique was used to monitor VCI-V concentration of oil blend 115A during an engine test discussed in a subsequent section of this report.

TABLE 3. Preservative Oil Properties II

	MIL-L-21260C AL-14777	VCI Blend 115A AL-15052	MIL-P-46002 AL-14778
K. Vis at 40°C, cSt	90.31	90.06	11.10
K. Vis at 100°C, cSt	10.79	ND*	ND
VI	103	ND	ND
TAN	1.9	2.2	13.7
TBN (D 664)	3.1	7.2	11.4
N, %	0.039	0.111	0.270
S, %	0.72	0.64	0.21
Sulfated Ash, %	0.85	1.05	ND
GCBP Distribution, °C at wt% off			
1	335	337	238
5	391	390	251
10	412	411	264
20	431	432	280
30	445	446	295
40	457	459	308
50	471	472	321
60	485	487	338
70	502	505	359
80	526	532	389
90	>600	>600	451
Residue, wt%, 600°C	10.7	10.9	4.8
Elements, ppm by ICP			
Ca	660	662	1
Ba	3	1510	<1
Mg	360	333	<1
Zn	1454	1422	4
P	972	943	12
B	<1	<1	<1
Si	4	5	<1
Cu	<1	<1	<1
Na	512	580	<1
Other	-	-	Flash Point 275°F (135°C)

* ND = Not Determined.

TABLE 4. Experimental VCI Oils Formulated by Belvoir Fuels and Lubricants Research Facility — Additive VCI-V

Oil Component/Code	AL-14777	AL-14778	115A	115B	115C
AL-14777, MIL-L-21260	100	--	95	97	99
AL-14778, MIL-P-46002, Grade 1, vol%	--	100	--	--	--
AL-14691, Additive VCI-V Concentrate, vol%	--	--	5	3	1
Test Results					
Corrosion Protection, Humidity Cabinet, 30 days, FTM-791 Method 5329.2	No Rust	Not Tested	No Rust	No Rust	No Rust
Vapor Phase Protection, Sec 4.10.2 of MIL-P-46002, SAE 1009 Steel Coupons					
Grade 1 Conditions	Fail	Pass	BL* Fail	Fail	Fail
Grade 2 Conditions	Fail	Not Tested	Pass	BL Pass	Fail

* BL = Borderline.

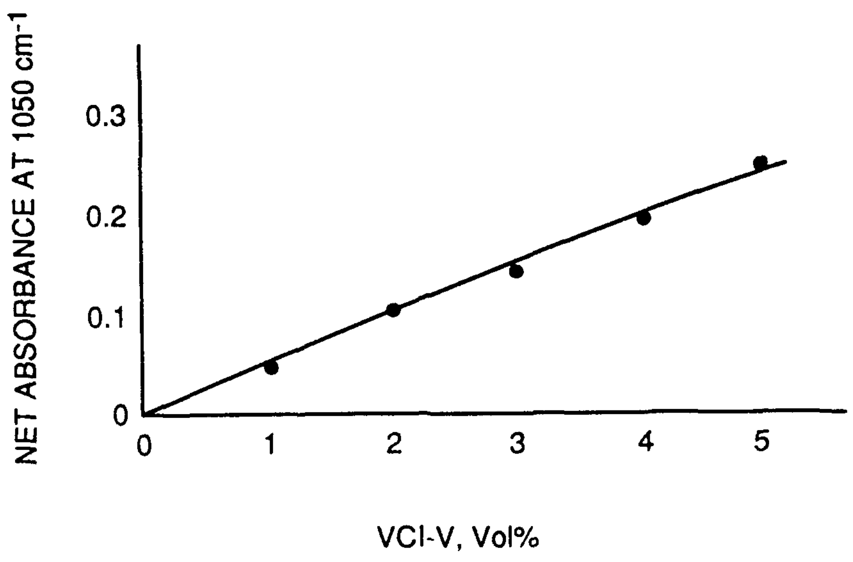

Figure 3. Standard curve for VCI-V concentration

A second commercial additive, designated VCI-C, was received late in the program and briefly evaluated. Additive VCI-C contained nitrogen at 0.9 wt% and calcium at 0.6 wt%. Several blends of MIL-L-21260 (AL-14777) SAE-30 grade oil and VCI-C were made and evaluated in the Vapor Phase Protection Test Method 4.10.2 from MIL-P-46002. Results are shown below:

	AL-14777	613A	613B	613C	614D
AL-14777, MIL-L-21260, vol%	100	90	95	99	99.5
AL-15175, Additive VCI-C, vol%	0	10	5	1	0.5
Vapor Phase Protection, Sec 4.10.2 of MIL-P-46002, SAE 1009 Steel Coupons Grade 2 Conditions	Fail	Pass	Pass	BL* Fail	Fail

* BL = Borderline.

Overall, additive VCI-C provided approximately the same level of protection as VCI-V at a given additive treatment rate.

A third commercial additive, designated VCI-E, was investigated. Additive VCI-E contained barium (1024 ppm), calcium (390 ppm), and nitrogen 1.16 wt% and had a TBN of 54. Blends of 2, 4 and 5 vol% additive VCI-E in AL-14777, MIL-L-21260, failed the VPP test grade 2 conditions. Thus, no further evaluation of VCI-E was conducted.

D. Single-Cylinder Engine Tests

The single-cylinder Caterpillar 1H2 test is used to evaluate piston cleanliness of light-medium duty diesel engine oils (7), and was a requirement of MIL-L-21260C. The following three oils were evaluated by the 1H2 procedure:

- PEO-30, MIL-L-21260, AL-14777
- PEO-30 + 0.7 wt% VCI-A, AL-15293
- PEO-30 + 5 wt% VCI-V, AL-15052

Summarized results of the Caterpillar 1H2 tests are presented in TABLE 5 and are compared to the requirements of MIL-L-21260C. Complete Caterpillar 1H2 test reports are included as Appendix B. The neat PEO-30 (AL-14777) was a clean pass with very low top groove fill percent and low weighted total piston deposit. Both experimental oils containing VCI material failed the 1H2 weighted total piston deposit requirement. For both oils, most of the weighted deposit came from lacquer on No. 3 and 4 lands and carbon in No. 2 groove.

TABLE 5. Caterpillar 1H2 Tests

Oil	Top Groove Fill, %	Weighted Total Deposit
MIL-L-21260C Requirements	45 Max	140 Max
AL-14777 (PEO)	10	74
AL-15293 (PEO + 0.7 vol% VCI-A)	7	403 = Fail
AL-15052 (PEO + 5 vol% VCI-V)	19	528 = Fail

The amount of VCI-V additive present in the oil during the 1H2 test was determined using differential infrared analysis. The results shown in TABLE 6 reveal that the additive content leveled off at about 3.5 vol% (70 percent of original amount). The 120-, 240-, and 480-hour used oil samples were evaluated in the Vapor Phase Protection (VPP) test of MIL-P-46002, and all three samples failed at grade 2 conditions. As shown earlier in TABLE 4, fresh oil formulated with 3 vol% VCI-V was a borderline pass; thus, it appears the engine environment degrades the vapor phase protection of additive VCI-V as the 480-hour used oil sample, which contained 3.6 vol% VCI-V, was a fail in the VPP test.

TABLE 6. VCI-V Content of Used Oil From Caterpillar 1H2 Test

Test hr	Vol% VCI-V by IR
1	4.2
2	4.0
3	3.9
4	3.8
5	3.8
6	3.8
7	3.8
8	3.6
9	3.5
10	3.7
15	3.6
20	3.6
25	3.7
30	3.5
100	3.6
120	3.3
225	3.5
240	3.4
280	3.3
320	3.4
400	3.7
440	3.4
480	3.6

E. Engine Storage

1. Engines

A 3-year outside storage program was conducted to evaluate (a) experimental PEO containing VCI-B additive, and (b) a simplified diesel engine preservation technique. The diesel engines involved in the storage test were four DDC 6V-53T engines and two GM 6.2 L engines. Engine specifications are presented in TABLE 7.

TABLE 7. Characteristics of Test Engines

DDC 6V-53T Engine

Model:	5063-5395
Engine Type:	Two-Cycle, Compression Ignition, Direct Injection Turbo-Supercharged
Cylinders:	6, V-Configuration
Displacement:	5.21 L (318 cubic inches)
Bore:	9.8 cm (3.875 inches)
Stroke:	11.4 cm (4.5 inches)
Compression Rate:	18.7:1
Fuel Injection:	DD Unit Injectors, N-70
Rated Power:	224 kW (300 bhp) at 2800 rpm
Rated Torque:	858 NM (633 lb-ft) at 2200 rpm

GM 6.2L Engine

Model:	GM 6.2 L
Engine Type:	Four-Cycle, Compression Ignition, Ricardo Comet V Combustion Chamber
Cylinders:	8, V-Configuration
Displacement:	6.217 L (379 cubic inches)
Bore:	10.1 cm (3.98 inches)
Stroke:	9.7 cm (3.82 inches)
Compression Rate:	21.3:1
Fuel Injection:	Stanadyne DB-2 Fuel Injection Pump, Bosch Pintle Injectors
Rated Power:	116 kW (155 bhp) at 3600 rpm
Rated Torque:	355 NM (262 lb-ft) at 2200 rpm

2. Lubricants

The following lubricants were used to preserve the three test and three control engines:

Control Engines — Two 6V-53T engines and one 6.2 L engine

Engine Oil: AL-15435, MIL-L-21260, SAE 30, PEO-30

Fueled with: AL 15344, MIL-L-21260, SAE 10W, PEO-10

Test Engines — Two 6V-53T engines and one 6.2 L engine

Engine Oil: AL-15434, PEO-30 + 0.5 wt% VCI-B

Fueled with: AL-15437, PEO-10 + 0.5 wt% VCI-B

Properties and inspections of these oils are presented in TABLE 1. Fuel AL-15437 was not analyzed.

3. Preservation Procedure

The technique to preserve the engines involved charging the sump with preservative oil, starting the engine on diesel fuel, switching the fuel to preservative oil, and then running the engine until oil exits the fuel return line. While the engine was running, preservative oil was sprayed into the air intake with a commercial spray paint gun at 50 psi for 1.5 to 2.0 minutes. The flow rate of the oil spray was estimated at 5 ounces per minute. During preservation, engine oil sump temperature did not exceed 130°F (54°C) to minimize VCI component loss. The engine was stopped by blocking air from entering the air intake.

Two 6V-53T engines and one 6.2L engine were preserved with the experimental preservative oil, which contained a vapor phase corrosion inhibitor (VCI-B) additive. A like number of control engines were preserved with MIL-L-21260 oil. After preservation, all air intakes on the engine

were sealed, and the engine was placed in a box for storage. The boxes were not sealed, but had openings that simulated an engine compartment of a vehicle.

4. Storage Location/Duration

Engine storage was conducted at Corpus Christi Army Depot (CCAD). CCAD is located on Corpus Christi Bay adjacent to the Gulf of Mexico, which provided a severe test environment with salt water in the air. Fig. 4 shows the exact engine storage location of CCAD, and its proximity to the Corpus Christi Bay. Figs. 5 and 6 are photographs of the enclosed engine storage area containing the engines stored in boxes.

The engines were preserved in late October 1986 and placed in storage at CCAD during November 1986. One control and one test 6V-53T engine were retrieved from CCAD at the end of one year. The engines were inspected, represerved, and returned to storage for the remaining two years. Thus, one each control and test 6V-53T engine were inspected at 1, 2, and 3 years. Both 6.2L engines were inspected after 3 years of storage. All engines were moved to San Antonio, TX, for approximately 3 months during the fall of 1988 due to a hurricane threat at CCAD. Early in 1989, the engines were returned to CCAD. Throughout the 3 years of storage, BFLRF personnel made quarterly inspections of the storage site. No problems were observed during storage.

5. Results — 6V-53T Engines

After storage, the engines were returned to BFLRF for disassembly and inspection. The following summary presents the 6V-53T engine number and oil identity used for each engine:

	Oil	
Year	PEO	PEO + VCI-B
1	ENG 14	ENG 9
2	ENG 14	ENG 9
3	ENG 8	ENG 15

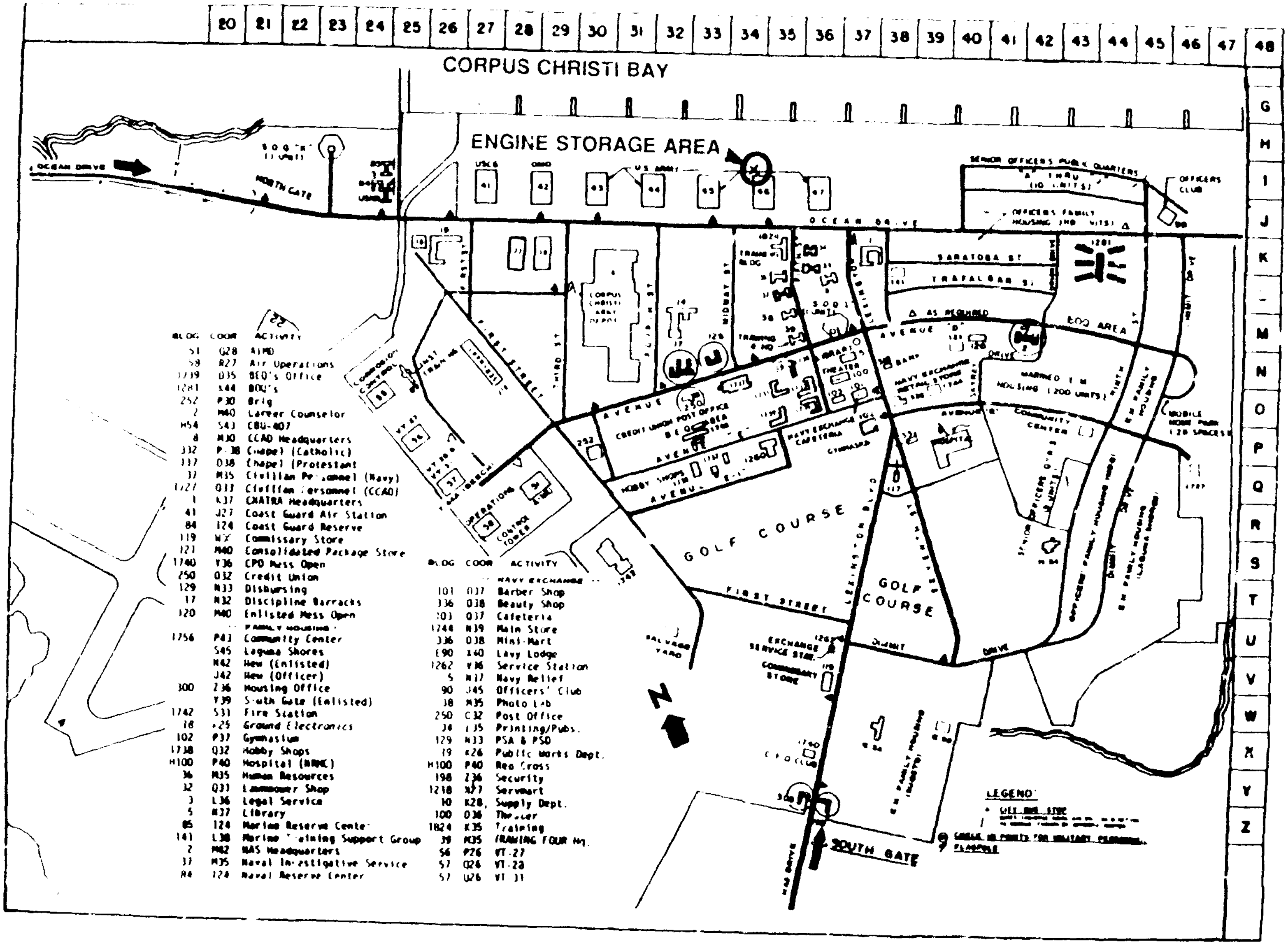

Figure 4. Map of CCAD storage area

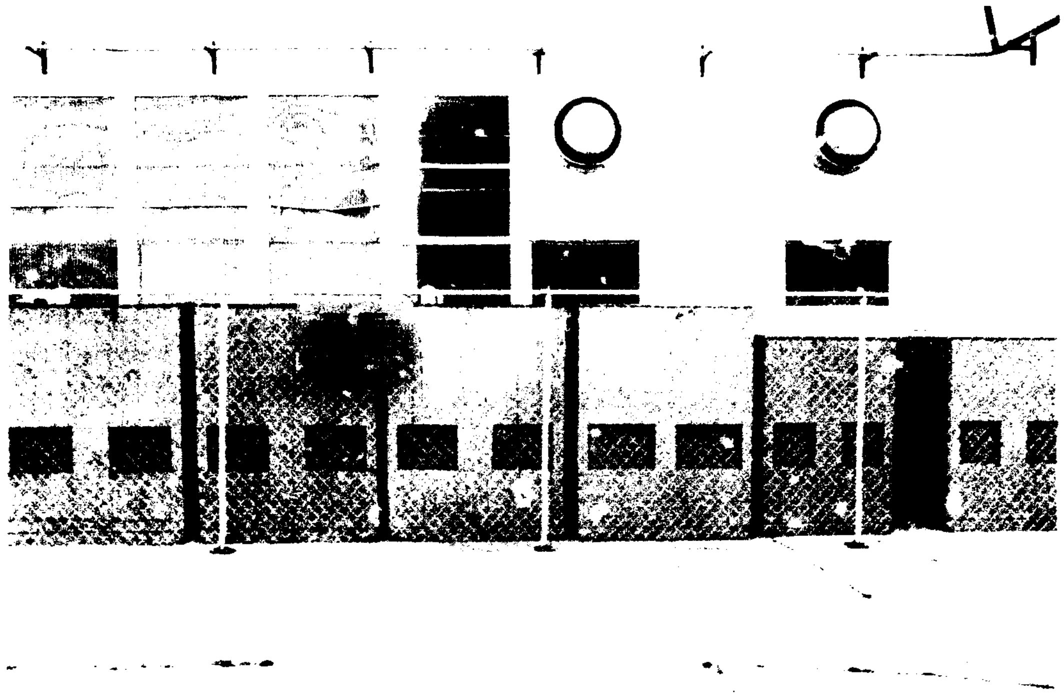

Figure 5. Engine storage area at CCAD

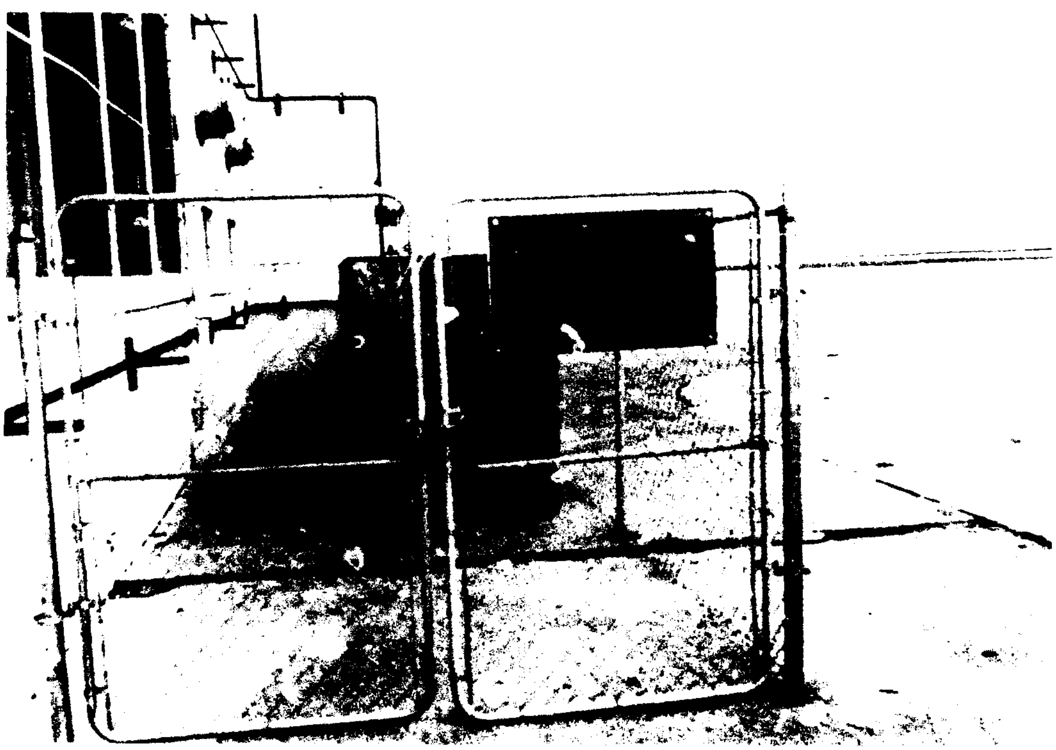

Figure 6. End view of storage area

Fig. 7 shows the exterior of 6V-53T engine No. 9 after 2 years of storage, while Fig. 8 shows engine No. 8 after 3 years of storage. Severity of the storage environment is evident from the rust and corrosion on unprotected exterior engine parts.

TABLE 8 summarizes the CRC rust merit ratings (10 = clean) for the 6V-53T engines after 1, 2, and 3 years of storage. At 1 year, both engine Nos. 14 (PEO) and 9 (PEO + VCI-B) had light rust in the following areas: air box covers, rocker arm covers, and oil pans. The oil pickup tubes had moderate rust (PEO + VCI-B) and light rust (PEO). The 6V-53T engines were assembled for BFLRF by another SwRI division as these engines were surplus oil test engines previously used for FTM-355 tests. Due to the location and nature of this rust and considering the prestorage photos of other engine parts used to build the test engines, it is likely that the rust in these areas occurred prior to preservation. The remainder of the engine preserved with neat PEO was rust free and in excellent condition. The engine preserved with PEO + VCI-B had light rusting on the cylinder liner bores, which covered approximately 50 percent of the internal surface area. Since the engine was operated prior to preservation, this rust is assumed to have occurred after preservation. Many of the oil-wetted surfaces in this engine had a very slight

TABLE 8. CRC Rust Merit Ratings (10 = Clean) — 6V-53T Engines After Storage

	1 Yr		2 Yr		3 Yr	
Engine Area	PEO	PEO + VCI-B	PEO	PEO + VCI-B	PEO	PEO + VCI-B
Rocker Covers	6.42	8.22	9.10	9.42	7.72	7.50
Top Deck	10.0	9.72	9.78	9.85	7.90	9.55
Rocker Pedestals	10.0	7.30	10.0	8.30	9.85	10.0
Rocker Arms	10.0	9.05	9.92	7.60	9.50	9.25
Oil Pan	9.65	9.55	9.70	9.98	10.0	5.95
Oil Pickup Tube	7.95	4.20	9.50	9.30	8.25	5.38
Air Box Covers	9.65	6.92	9.19	9.58	7.59	7.52
Liners	10.0	8.14	8.16	8.15	8.20	7.96
Camshaft Lobes	10.0	9.21	9.88	9.82	9.82	9.95
Bottom - Con Rod Cap	9.93	9.02	9.36	9.68	9.91	9.42
Average	9.36	8.13	9.46	9.17	8.87	8.25

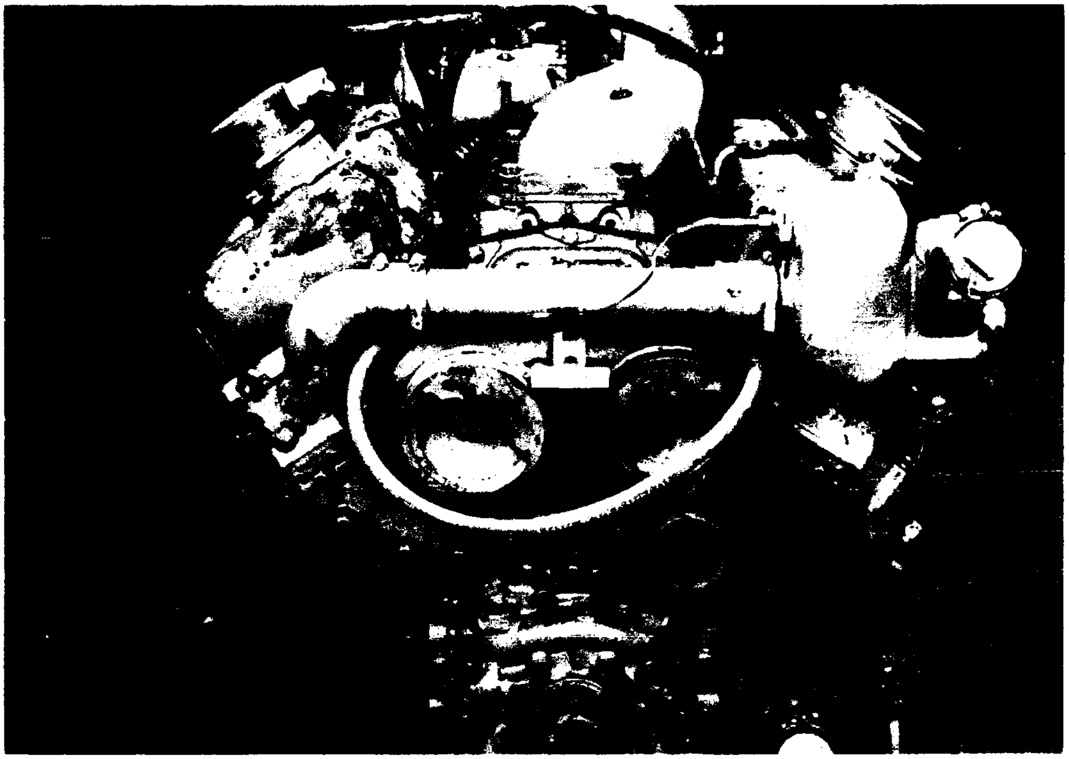

Figure 7. 6V-53T engine No. 9 after 2 years of storage

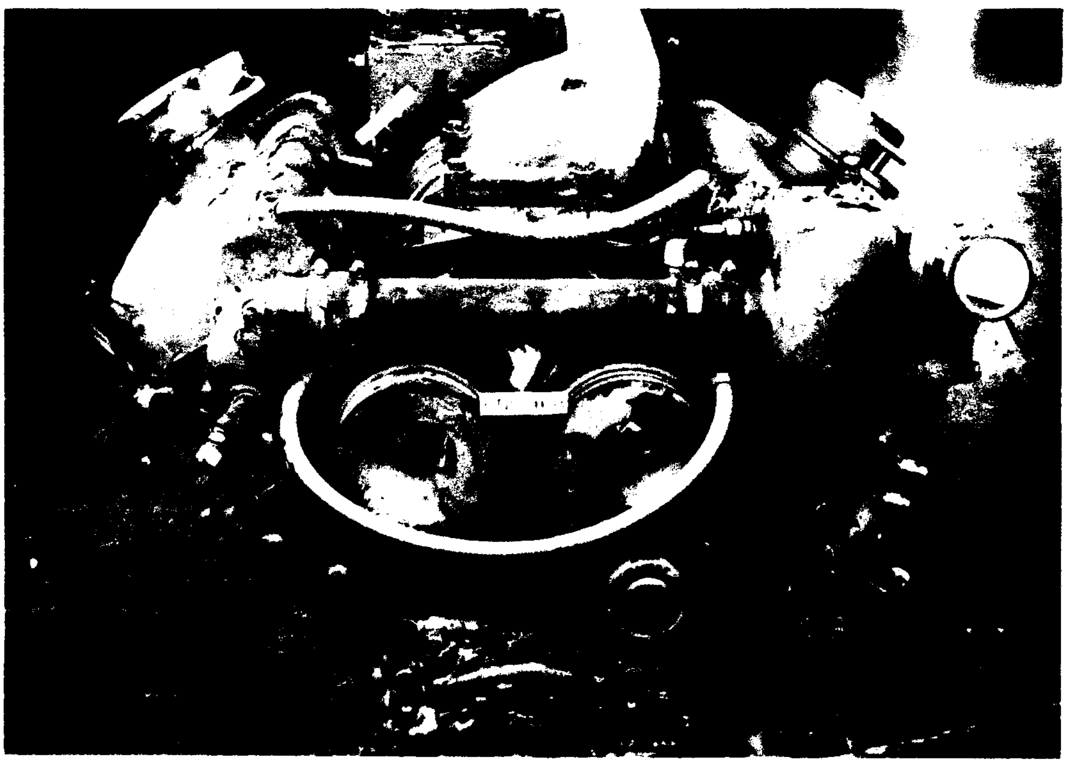

Figure 8. 6V-53T engine No. 8 after 3 years of storage

brownish tint that was not present in the neat PEO engine. Despite the minor differences in engine condition, both engines appeared to have been adequately preserved for 1 year as no severe rust in critical operating areas (such as the piston rings and ring grooves) was observed for either engine. The lightly rusted parts were cleaned by BFLRF, and the engines were represerved, and then returned to CCAD for 2 years of uninterrupted storage. Thus, the 2-year storage 6V-53T engines had clean, rust-free surfaces prior to preservation. It was not assured that the 1-year and 3-year storage 6V-53T engines were rust-free prior to preservation. The 3-year oil pan and pick-up tube for engine No. 15 (PEO + VCI-B) contained heavier rust, again probably due to some pre-existent rust. No consistent trends were observed with respect to oil type and locational rust ratings. Representative photographs of engine parts are presented in Appendix C. All engines were judged as adequately preserved for 1, 2, and 3 years with both oil formulations. No advantage was observed for the engines preserved with PEO + VCI-B.

6. Results — 6.2L Engines

Summary TABLE 9 contains the CRC rust merit ratings (10 = clean) for the 6.2L engines after 3 years of storage. These engines were cleaned, assembled, and preserved by BFLRF. Figs. 9 and 10 are photographs of the exterior of 6.2L engines after 3 years of storage at CCAD. The

TABLE 9. CRC Rust Merit Ratings (10 = Clean) — 6.2L Engines After 3 Years of Storage

Engine Area	PEO	PEO + VCI-B
Rocker Covers	8.48	8.64
Top Deck	9.41	9.32
Rocker Pedestals	10.0	9.35
Rocker Arms	9.85	8.10
Oil Pan	8.80	6.00
Oil Pickup Tube	10.0	9.15
Cylinder Bores	9.41	9.45
Bottom - Con Rod Cap	9.08	9.20
Average	9.38	8.65

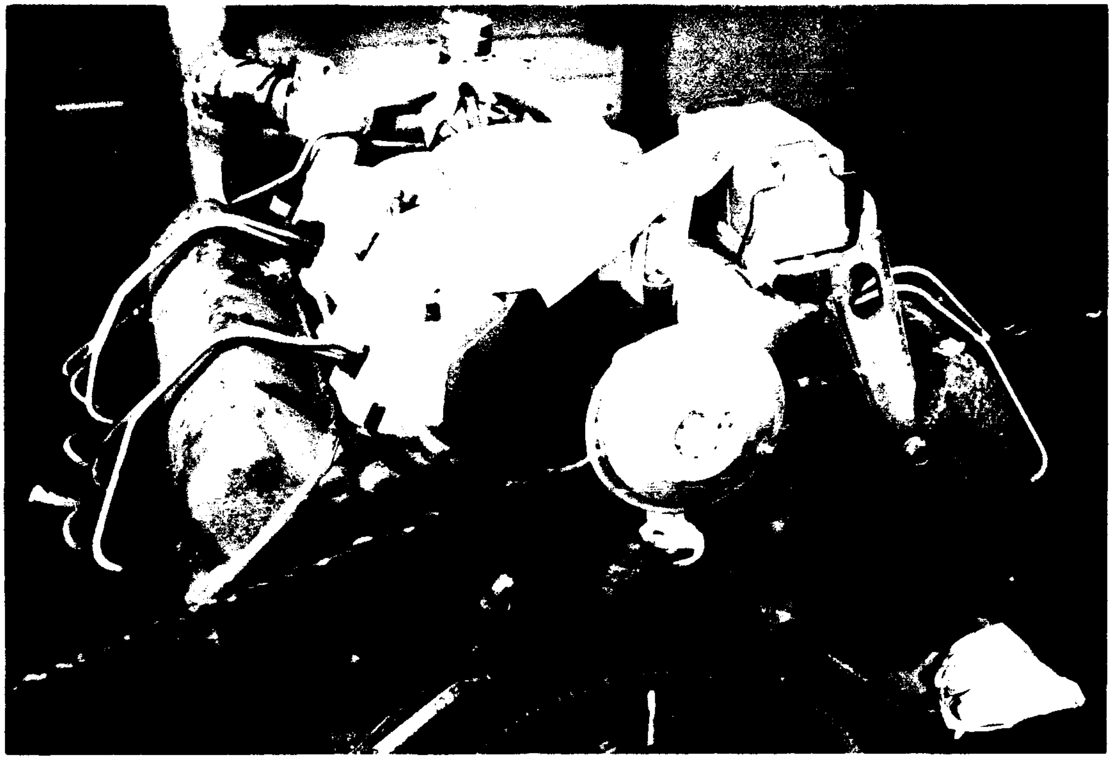

Figure 9. 6.2L engine (PEO) after 3 years of storage

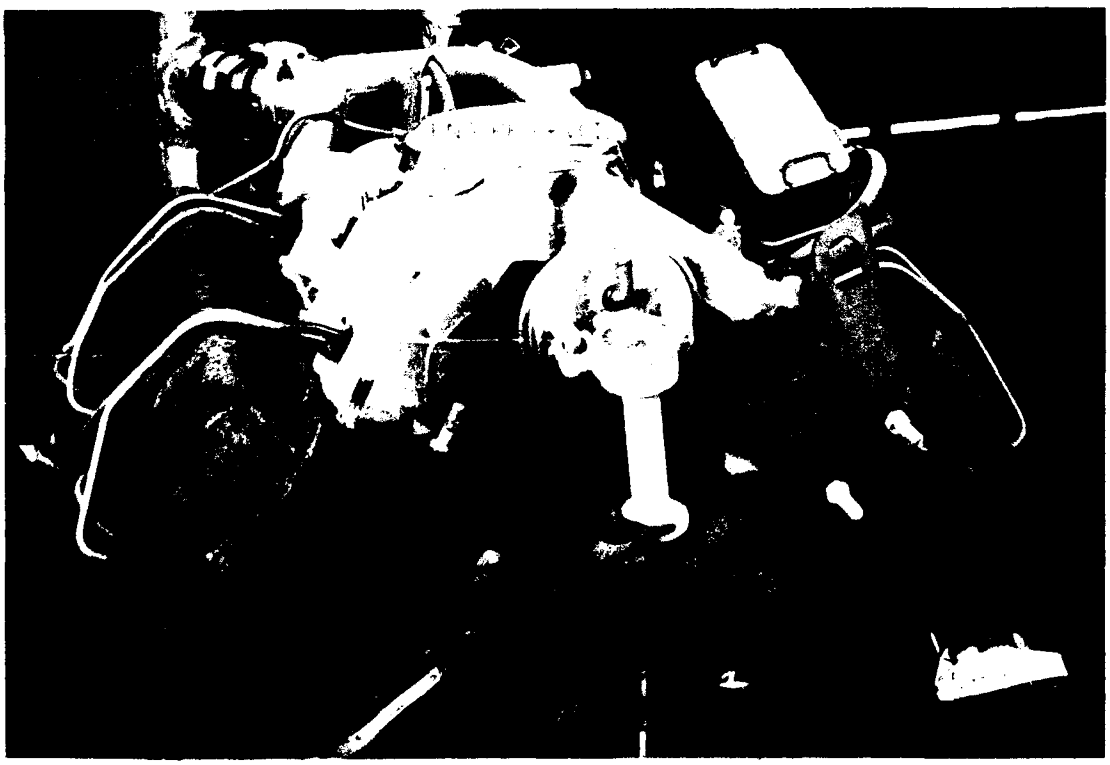

Figure 10. 6.2L engine (PEO + VCI-B) after 3 years of storage

severity of the storage environment is shown by the rust and corrosion of unprotected exterior engine parts. The engines had similar rust ratings except for increased rocker arm, oil pan and oil pickup tube rust in the engine preserved with PEO + VCI-B. Overall, the neat PEO provided slightly better protection than the PEO + VCI-B. The engines were judged to have been adequately preserved for 3 years using the simplified procedure. Photographs of representative engine parts are presented in Appendix D.

F. Compatibility of Fuel System Materials and Components With Oil Containing VCI

Storage tests were conducted to determine the compatibility of oil containing VCI material with materials and components typically found in diesel engines. The materials investigated included 13 different metal coupons and 8 different elastomer types. In addition, compatibility of VCI oil with four different fuel filter types and with the polyurethane flex ring from a Stanadyne fuel injection pump was determined. In a related issue, because of reported material incompatibilities with MIL-P-46002 oil (8), the effects of this oil on fuel filters, flex rings, and an entire Stanadyne fuel injection pump were investigated.

1. Metal Coupons

The following 13 metals were procured for compatibility testing with an experimental oil AL-15434 (PEO-30 + 0.5 percent VCI-B):

Copper, Electrolytic (QQ-C-576)
Aluminum (QQ-A-250/4E)
Steel (ASTM A 366, Class 1)
Zinc (QQ-Z-301C)
Cadmium (QQ-A-671)
Magnesium (QQ-M-44B, AZ31B)
Lead (QQ-L-201F(2), Grade B)
Brass (QQ-B-613D, Composition 342)
Bronze (QQ-B-728, Class A)
Tin (MIL-T-12076A, Grade B)
Babbit
Silver
Nickel

The panels were prewashed with n-heptane and iso-octane and then placed in sealed glass storage vessels. The coupons were suspended so that 50 percent of each panel was immersed in the test oil and 50 percent was in the vapor space above the liquid. The panels were stored in triplicate for 1, 2, and 3 years. At the end of each storage period, the coupons were dip rinsed in n-heptane and then iso-octane and air-dried before inspection. The same visual rating procedure was used for both liquid- and vapor-exposed areas. The demerit scale was 0 = clean, like new and 10 = heavy discoloration or corrosion. Average ratings of the metal coupons for 1, 2, and 3 years are presented in TABLE 10. Medium discoloration, which increased with time, was observed for silver in the liquid phase. The magnesium was unusual because the vapor phase discoloration was greater than that of the liquid phase. All panels that contained copper (brass, bronze, and copper) experienced medium to heavy discoloration in the liquid phase. By far, the lead coupons were most affected by exposure to the oil and vapor. The lead panels had heavy oxidation in the oil phase. All other metals had very light discoloration. Overall, the oil containing VCI-B additive had acceptable compatibility with all metal coupons except lead, copper, brass, and bronze. The compatibility with lead, copper, brass, and bronze coupons should be further examined to define the exact nature of these incompatibilities and relate this information to engine hardware life.

2. Elastomers

Compatibility of eight different elastomers was determined with five different oils: PEO-30 (AL-15435), PEO-30 + 0.3 wt% VCI-B (AL-16240), PEO-30 + 0.5 wt% VCI-B (AL-15434), PEO-30 + 0.7 wt% VCI-B (AL-16241), and MIL-P-46002 (AL-15160). The eight elastomers tested are listed below:

1. Medium Nitrile
2. Low Nitrile
3. High Nitrile
4. Polyester Polyurethane
5. Polyether Polyurethane
6. Fluorosilicone
7. Teflon®
8. Viton®

TABLE 10. Visual Inspection of Metal Coupons After Storage (0 = Clean, 10 = Heavy Discoloration or Corrosion)

Year	Metal Type	Average Rating In Vapor	Average Rating In Liquid
1	Copper	1	7
2	Copper	1	10
3	Copper	1	10
1	Zinc	1	2
2	Zinc	1	1
3	Zinc	1	1
1	Brass	1	9
2	Brass	2	10
3	Brass	2	10
1	Steel	1	1
2	Steel	1	1
3	Steel	1	1
1	Silver	2	4
2	Silver	2	5
3	Silver	2	7
1	Magnesium	3	2
2	Magnesium	4	3
3	Magnesium	4	3
1	Bronze	1	3
2	Bronze	2	5
3	Bronze	2	5
1	Nickel	1	1
2	Nickel	1	1
3	Nickel	1	1
1	Cadmium	1	2
2	Cadmium	2	2
3	Cadmium	3	4
1	Lead	3	6*
2	Lead	7	9*
3	Lead	7	9*
1	Babbit	1	1
2	Babbit	1	1
3	Babbit	1	1
1	Tin	1	2
2	Tin	1	1
3	Tin	1	1
1	Aluminum	1	2
2	Aluminum	1	1
3	Aluminum	1	2

* Panels appeared to be oxidized.

Each elastomer type was stored in air, submerged, and in the vapors phase of each of the five oils for 1, 2, and 3 years. The storage was at ambient outdoor conditions in San Antonio, TX. In accordance with Belvoir RDE Center instructions, the elastomer dumbbells were stored in a 9:1 volumetric ratio, i.e., 130 mL fluid volume for five dumbbells of a given type in a glass container.

Fig. 11 shows a representative submerged sample, Fig. 12 shows a representative vapor space storage container, and Fig. 13 shows an air storage container. A complete listing of the elastomer test matrix is presented in Appendix E.

After 1, 2, and 3 years of storage, the elastomers were returned to Belvoir RDE Center for physical property determinations. These results will be presented in a separate Belvoir RDE Center report.

3. Flex-Rings

The Stanadyne fuel injection pump used in U.S. Army CUCVs and HMMWVs contains a polyurethane flex-ring. Since there was concern about the effect of VCI materials on this flex-ring, a storage compatibility test was conducted. Flex-rings were stored half submerged in the following oils: PEO-30 (AL-15435), PEO-30 + 0.5 wt% VCI-B (AL-15434), and MIL-P-46002 (AL-15160). After 1, 2, and 3 years of outdoor storage at ambient conditions in San Antonio, TX, all flex-rings were discolored in those areas exposed to the liquid phase. Fig. 14 shows the flex-rings after 3 years of storage. No discoloration appeared where the flex-rings were exposed to the vapor phase, and all flex-rings were judged to be compatible with all three oils: PEO-30, PEO-30 + 0.5 wt% VCI-B, and MIL-P-46002.

4. Fuel Filters

Fuel filters come into contact with preservative engine oil when it is used to fuel the engine during preservation. Thus, the compatibility of fuel filter types found in U.S. Army equipment

Figure 11. Representative submerged storage

Figure 12. Representative vapor storage

Figure 13. Representative air storage

was determined with PEO-10 and PEO-10 + 0.5 wt% VCI-B. There are currently four basic types of fuel filters used in Army ground vehicles, and Fig. 15 shows an example of each fuel filter type:

- Pleated Paper
- Wound Cotton String
- Cotton Sock
- Phenolic Resin

Examples of each fuel filter type were immersed in the test oil and stored in sealed glass jars at outside ambient temperature

AL-15160-L
MIL-P-46002

AL-15435-L
PEO-30

AL-15434-L
PEO-30+ 0.5 wt%
VCI-B

NEW

Figure 14. Flex-rings after 3 years of storage

Pleated Paper | Wound Cotton String | Cotton Sock | Phenolic Resin

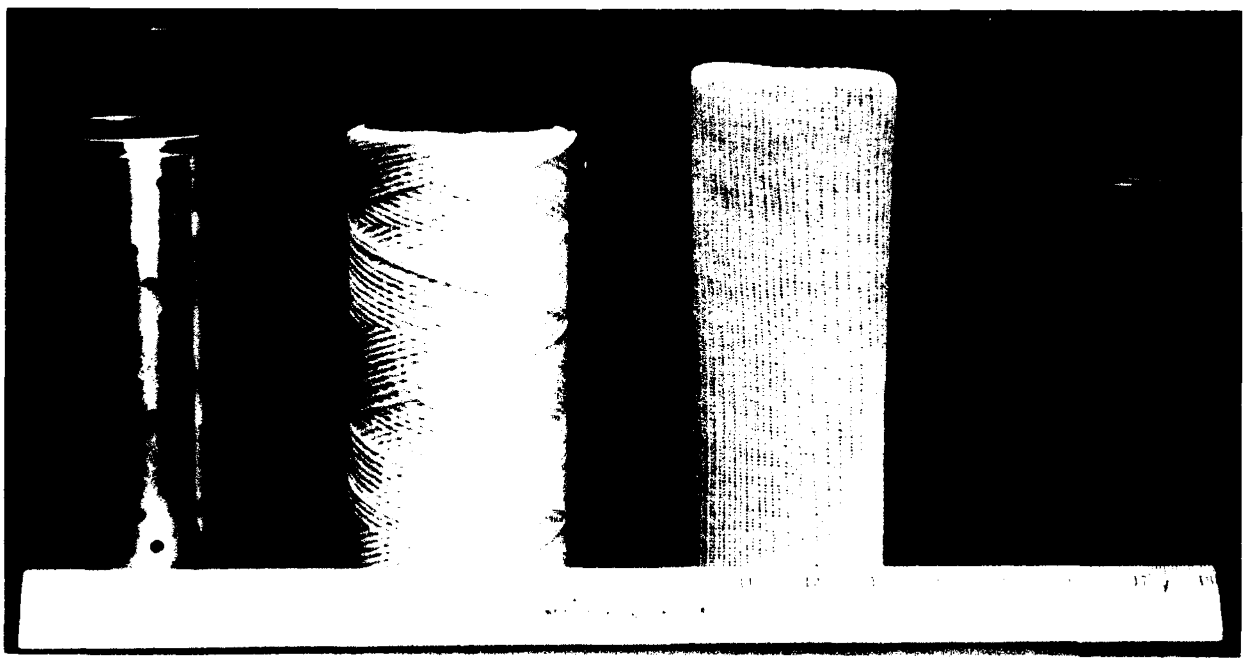

Figure 15. Fuel filter types

conditions in San Antonio, TX, for 1, 2, and 3 years. Physical dimensions of the filters were measured before and after storage and are presented in Appendix F. None of the filters had a major change in dimensions for either oil type or with increasing storage duration. Filter performance was determined using the BFLRF fuel filter test rig.(9) A photograph of the rig is shown in Fig. 16, and a schematic diagram is shown in Fig. 17. The following parameters were measured using the filter rig:

- Filter performance time to a standard 15-psi pressure drop
- Media migration as measured during a 15-minute run with no contaminant injection
- Solids removal (AC Test Dust)

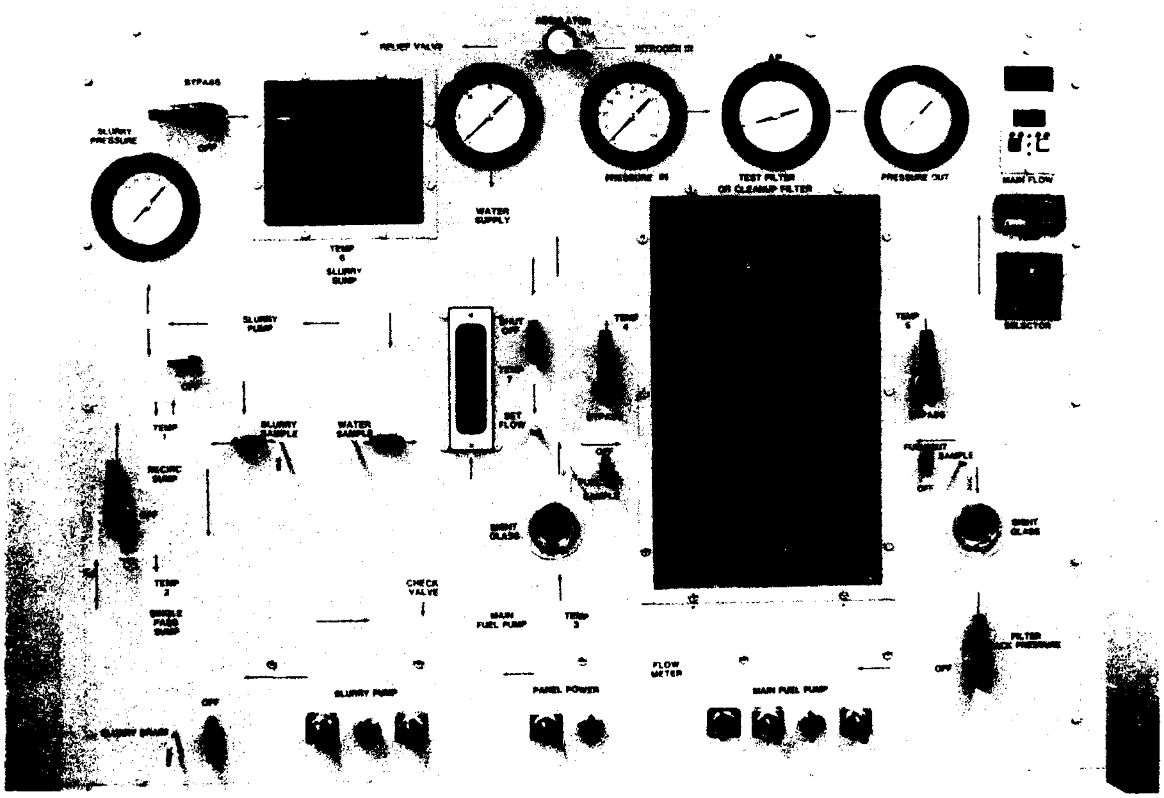

Figure 16. <u>Photo of BFLRF fuel filter test rig</u>

TABLE 11 shows the summarized results for time to a 15-psi pressure drop. An increased time to the standard 15-psi pressure drop was observed for all fuel filter types in both oil types with increased storage duration. A representative time-to-pressure drop plot is shown in Fig. 18. No substantial effects were observed with respect to the presence of VCI-B additive.

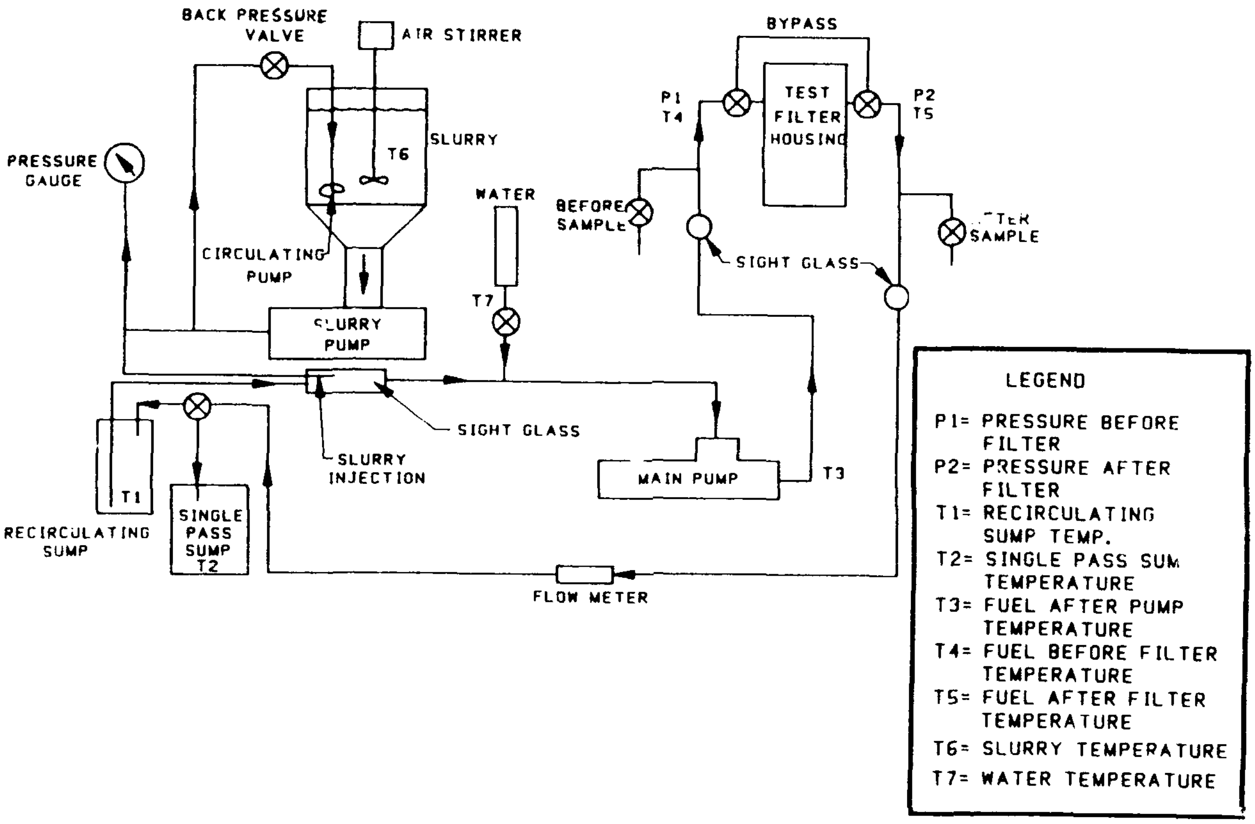

Figure 17. Schematic of BFLRF fuel filter test rig

TABLE 11. Fuel Filter Performance: Time to 15-psi Pressure Drop

Filter Type	New Fuel Filters (Not Exposed)	Filters Exposed 1 Year		Filters Exposed 2 Years		Filters Exposed 3 Years	
		PEO-10	PEO-10 + VCI-B	PEO-10	PEO-10 + VCI-B	PEO-10	PEO-10 + VCI-B
Phenolic Resin	47 min	29 min	40 min	56 min	105 min	>2 hr	94 min
Wound Cotton String	29 min	52 min	75 min	>2 hr	>2 hr	72 min	>2 hr
Pleated Paper	43 min	>3 hr	>3 hr	>2 hr	>2 hr	>2 hr	>2 hr
Cotton Sock	35 min	>3 hr	>3 hr	>2 hr	>2 hr	>2 hr	>2 hr

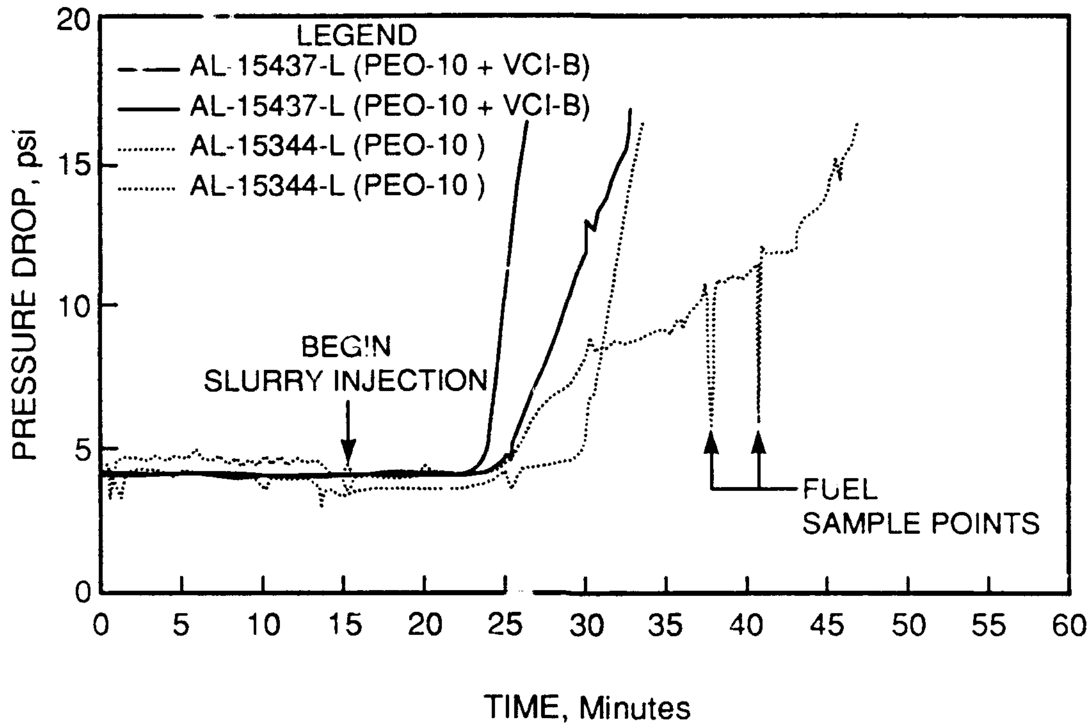

Figure 18. Time to 15-psi pressure drop
(Storage for 1 year at ambient phenolic resin filter)

TABLE 12 and Figs. 19 and 20 show average particulates removed/unit time after 1, 2, and 3 years of storage. The most evident effect was a decrease in average particulates removed with increased storage duration for all four filter types. At 3 years the pleated paper and cotton sock filters stored in PEO-10 had slightly better particulates removal than those exposed to VCI-B, while the phenolic resin and wound string had better particulate removal when VCI-B was present. For years 2 and 3, the phenolic resin filters stored in PEO-10 actually added material to the particulate content. In summary, after 2 and 3 years of exposure to either oil, filter particulate removal was substantially decreased.

5. Stanadyne Fuel Injection Pump -- Compatibility With MIL-P-46002

The compatibility of a Stanadyne fuel injection pump (6.2L engine) with MIL-P-46002 was determined. The pump was filled with MIL-P-46002 and stored for 3 years at CCAD. After storage, the pump was bench flow tested and found to be in acceptable condition. No leaks were

TABLE 12. Particulate Removal

	Filter Storage Evaluation, average milligrams particulates removed/unit time			
	Pleated Paper		Cotton Sock	
Years	PEO-10	PEO-10 + 0.5 wt% VCI-B	PEO-10	PEO-10 + 0.5 wt% VCI-B
1	10.4	7.4	11.2	11.6
2	6.4	7.3	2.0	2.8
3	6.0	3.0	8.7	2.4
	Phenolic Resin		Wound Cotton String	
Years	PEO-10	PEO-10 + 0.5 wt% VCI-B	PEO-10	PEO-10 + 0.5 wt% VCI-B
1	29.4	69.1	16.0	26.2
2	-2.4	4.7	6.2	5.9
3	-7.7	0.7	2.3	9.9

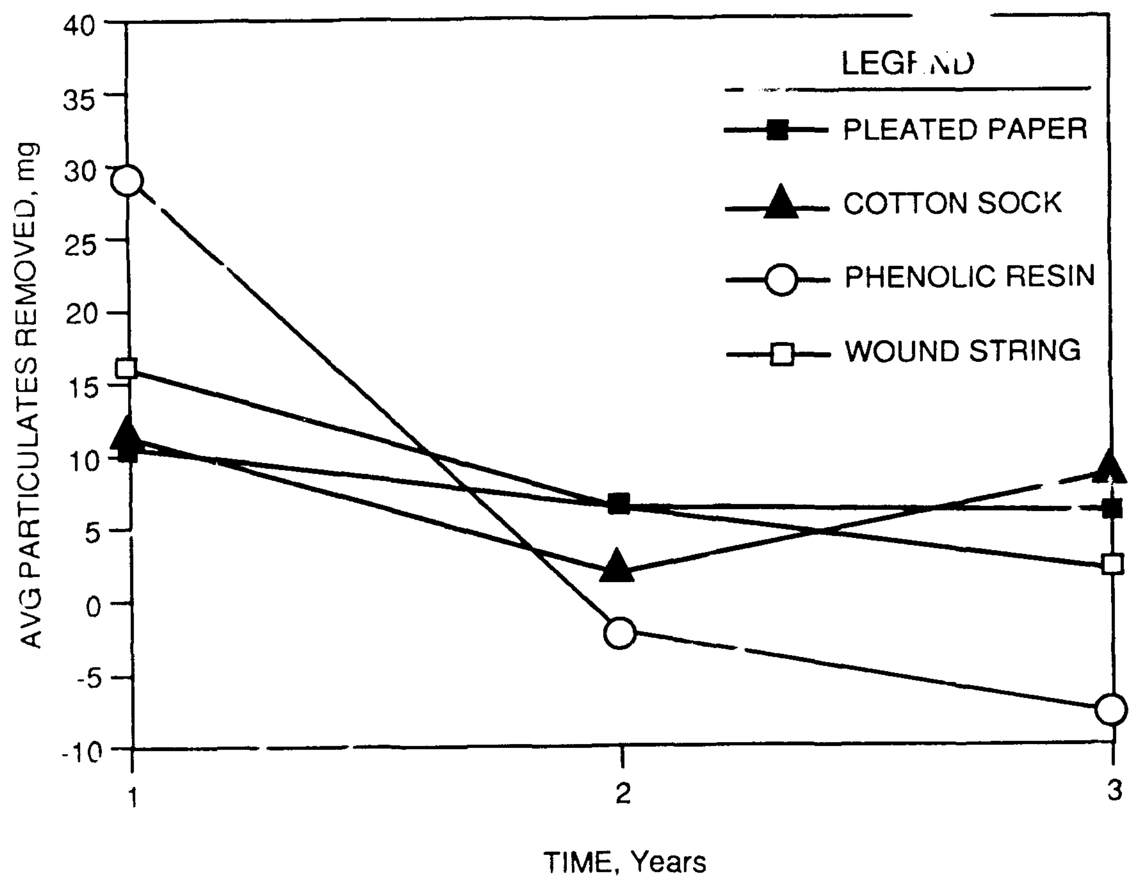

Figure 19. Filter storage evaluation — PEO-10

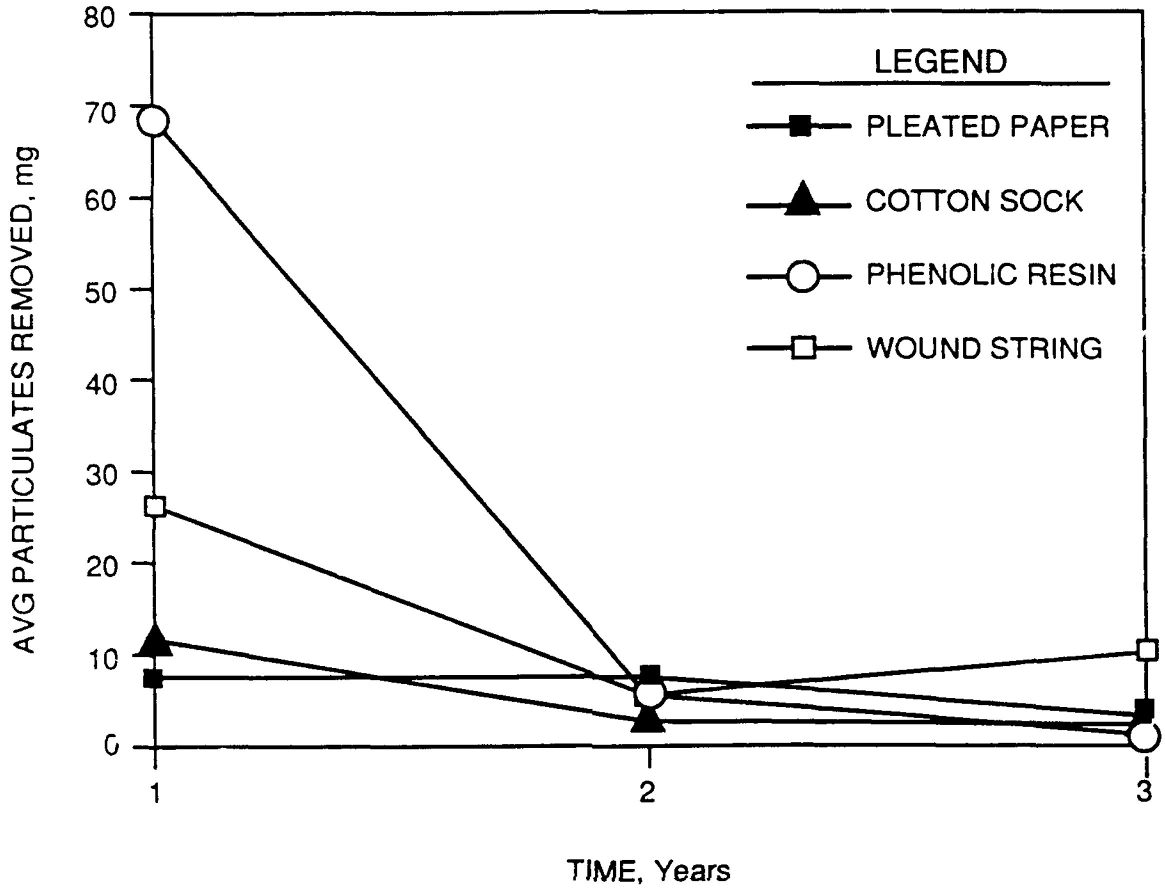

Figure 20. Filter storage evaluation — PEO-10 + 0.5 wt% VCI-B

observed, and fuel delivery was within specification. Thus, the Stanadyne fuel injection pump and MIL-P-46002 were judged to be compatible.

IV. CONCLUSIONS

Based on the results of the investigations conducted during this program, the following conclusions are presented:

- The simplified engine preservation procedure provided adequate engine protection for 3 years in a very severe environment.

- Engine oils meeting specification MIL-L-21260 provided satisfactory storage protection during the 3-year engine storage test.

- Experimental engine oil composed of MIL-L-21260 plus additive VCI-B provided satisfactory storage protection during the 3-year engine storage test. No advantage was observed for the oil containing VCI-B additive.

- Based on 3 years storage, the Stanadyne fuel injection pump (from GM 6.2L engine) was judged compatible with MIL-P-46002 oil.

- Flex-rings from the Stanadyne fuel injection pump were compatible with the following oils for up to 3 years: MIL-L-21260, MIL-L-21260 + VCI-B additive, and MIL-P-46002.

- Preservative engine oil MIL-L-21260 (PEO-30) containing additive VCI-B had acceptable compatibility for up to 3 years with all metal coupons examined except lead, copper, brass, and bronze. Further definition of the effect of VCI-type additives on these coupons is recommended.

- Fuel filter particulate removal performance was decreased with increased storage duration for all four fuel filter types, in PEO-10 oil with and without VCI-B. Fuel filter dimensions after storage and other measures of filter performance were essentially the same for PEO-10 with and without VCI-B.

- In Caterpillar 1H2 tests, two different VCI agents each caused the weighted total piston deposit to increase into the fail range. The deposit increase occurred in the second groove (carbon) and lacquer on the lower piston lands.

V. RECOMMENDATION

- The concept of including a VCI agent in MIL-L-21260 is still a valid goal. While the engines stored at Corpus Christi Army Depot were judged to be adequately preserved, they did have some rusting and corrosion on internal engine parts. A VCI containing oil that would prevent this rust is a desirable item. It is recommended that the goal of incorporating a VCI component in MIL-L-21260 engine oil be pursued as funding allows.

VI. LIST OF REFERENCES

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5. Fodor, G.E., "The Inhibition of Vapor-Phase Corrosion: A Review," Interim Report BFLRF No. 209 (AD A163430), prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, October 1985.

6. U.S. Military Specification MIL-P-46002, "Preservative Oil, Contact and Volatile Corrosion-Inhibited."

7. Caterpillar 1H2 Test, ASTM STP 509A.

8. LePera, M.E., Belvoir RDE Center, STRBE-VF, correspondence to S.J. Lestz, Belvoir Fuels and Lubricants Research Facility (SwRI), dated 24 April 1985.

9. Westbrook, S.R. and Bessee, G.B., "Automotive Diesel Fuel Filter Qualification Methodology and Preliminary Screening Results," Interim Report BFLRF No. 265, prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, December 1990.

APPENDIX A

Vapor-Space Corrosion Inhibited Operational Oils for Use in Spark and Compression Engine Lubricating Systems

Prepared by

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July 1986

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ABSTRACT

Incorporating specific vapor-space corrosion (VSI) inhibitors in operational motor oils has been shown by laboratory experiments to be feasible.

Based on these promising results, approximately 500 gallons of formulated oils were sent to the Southwest Research Institute for advanced testing.

The results of these tests have indicated that additional avenues of research should be pursued.

VAPOR-SPACE CORROSION INHIBITED OPERATIONAL OILS FOR USE IN SPARK AND COMPRESSION ENGINE LUBRICATING SYSTEMS

1. INTRODUCTION

Severe problems of corrosion in vehicle spark and compression engines have been identified by the Mobility Command, Research & Development Command, Ft. Belvoir, Virginia, and by the U.S. Army Tank and Automotive Command, Warren, Michigan. The problem concerns rusting of internal surfaces of engines not normally submerged in oil. Under normal conditions, these vapor spaces may contain water as condensate, moisture-laden air and air containing acidic components normally occurring in the atmosphere or as a result of engine combustion.

The corrosion product, rust, can present a major problem to the combat readiness of the military vehicle by scoring the gearing, clogging the filters and scoring the cylinder walls. The rust may contribute to an increase in oil consumption and encourage sludge formation.

Operational engine oils have two prime functions: to lubricate engine components and to serve as a heat transfer medium. To accomplish these functions, the oil must be fluid. Under normal conditions, and during periods of static use or storage, these oils flow from the vertical surface of the engine as a function of gravity, time and temperature to expose these surfaces above the level of the oil reservoir. It is at this time that the exposed ferrous surfaces are vulnerable to corrosion attack.

The concept for using a vapor-space corrosion inhibitor in operational oils is not new. Some 25 years ago, Ronco Laboratories, in cooperation with the Rock Island Arsenal Laboratory, developed the first soluble volatile corrosion inhibited oil. This VSI inhibited oil was developed for the protection of government-owned machine tools in long-term storage. The preservation technology practiced at that time was ineffective in preventing corrosion. To date, VSI technology has been concerned with the use of VSI in packaging of equipment or parts in storage or shipment rather than for the protection of equipment in operating status. With the exception of some minor modifications to the original VSI specifications, the state of the art has not essentially moved forward from the developmental formulations.

1A. REQUIREMENTS FOR VSI MATERIALS IN OPERATING OIL SYSTEMS

Many requirements for VSI materials may be listed. The VSI material must have sufficient vapor pressure to give an effective concentration of vapors in the vapor spaces at ambient temperatures, but must also be effective at elevated temperatures if the engine is operated for short intervals. There must be sufficient VSI component in the engine oil, so that the active material is not prematurely depleted over the long term. Once in the vapor

space, the VSI material must diffuse to the metal surfaces and condense to provide a protective coating. The VSI material must readily resolubilize into the matrix oil from the condensate. The material must be compatible with operational motor oils and meet the major requirements of MIL-L-21260 C, Grade 30. In addition, and of great importance, the additive must not present a toxicity problem when functioning under static conditions, under operating conditions, or cause undue disposal problems for spent motor oil.

2. EXPERIMENTAL APPROACH

The basic experimental approach was to evaluate the VSI additive in a qualified MIL-L-21260, Grade 30 oil under conditions which would closely approximate normal field conditions. We rejected the test method for evaluating the VSI in MIL-P-46002, which was designed for testing a concentrate VSI formulation, where the VSI component can be from 6% (weight) to 8% (weight). Further, the procedure for this test requires the premixing of the VSI inhibited oil with water in a relatively uncontrolled manner. This mixing process causes a leaching of the VSI inhibitor into the water prior to diffusion of the inhibitor into the vapor spaces. The VSI testing method as indicated in MIL-I-32210 was also rejected. This specification was designed to measure a concentrate formulation. The separation of oil and water in the test method can allow the water vapors to diffuse and condense before the VSI component. Further, the test temperatures required dictate that the VSI component have a much greater vapor pressure, which could lead to premature depletion of the VSI component. Of great importance, recognizing that the 21260 oil contains a substantial additive package, about 13% (weight), it was felt that any additional tier of VSI additive might cause compatibility problems and, at the least, possibly present unacceptable variations to the specification parameters of the 21260. It was decided to formulate the minimal, acceptable, effective additive in order to stay within the specification limitations.

2A. METHODOLOGY AND DETAILS OF THE APPARATUS

The methodology and apparatus we chose to use for this investigation were developed by the ASTM C-II Task Group for the purpose of testing and identifying the VSI material in turbine oils, at very low concentrations, to the order of .025% (weight). The test method more nearly approximates actual field conditions. The VSI material is extracted from the matrix oil and is condensed on the test coupon. Following this, the water vapor is introduced to the test coupon. This would be similar to the VSI component diffusing from the warm motor oil to condense on the cooling ferrous surfaces, followed by the introduction of moisture-laden air into the vapor space from the cooling process.

The apparatus is exceedingly sensitive to the extraction of even the slightest amount of volatile material at the maximum temperature set by the experimenter, and the constant cooling of the test coupon acts as a highly effective "magnet" for any volatiles in the matrix oil (Appendix A; Figures 1, 2 and 3).

It might be added that the method for preparing the steel test coupons by applying suitable abrasives while rotating the coupon in a drill chuck is

much easier and more effective than the method required for preparing coupons in MIL-P-46002 or MIL-I-2331.

3. RESULTS AND DISCUSSION

3.A. CHEMICAL INFORMATION BACKGROUND

Prior to any product development process, we investigated three areas of available information on volatile corrosion inhibitors which might be of value in our work. First, we surveyed the available literature from the various manufacturers of volatile inhibitors. In this area the only information available was the standard commercial literature such as that on various amines. We made inquiries of the developmental laboratories of larger companies as to any developmental products they might have which we could evaluate. With the exception of some developmental succinic anhydrides supplied to us for evaluation, there were no other candidates.

The second area of review was the current patent literature. A patent search was made in the area of corrosion. Numerous patents were issued concerned with aspects of corrosion. However, in all cases the literature cited was in the area of contact inhibitors, either aqueous or non-aqueous.

Our third possibility for review was information from consultants. While we received information about some possible candidate materials, in all cases testing proved them to be unusable.

3B. CHEMICAL EVALUATION

The traditional VSI component used in the MIL-P-46002 is an amine carboxylic acid reaction product. We tested this material with the neat 21260 oil and found it to be incompatible at concentrations as low as .1% (weight). We then evaluated the amine as to compatibility with the neat 21260 and found it to be compatible. The carboxylic acid was found to be incompatible with the neat 21260 to any appreciable degree.

We then proceeded to react a number of different amine-acid combinations in order to determine any suitable candidates for further evaluation. Our preliminary effort at the screening process for 20 candidates showed no real possibilities. Some of the candidates tested somewhat better than others; however, in no case were the differences significant (Chart No. 1). After the first screening of the 20 candidates, we elected to reduce the cooling temperature to the test coupon from 26° C to 21° C and increased the VSI concentration in two candidates from .5% (weight) to 1% (weight), in the expectation that we would provide a more favorable surface for the condensation of the increased VSI. We then added five more candidates to our screening list and proceeded to retest all the candidates at the revised levels. No product exhibited enough desired response to warrant further consideration (Chart No. 1).

One reaction product tested successfully in concentrations as low as .3% (weight). While the .3% coupon was not corrosion-free, the increment of improvement over the neat 21260 was highly significant. Testing at the .5% (weight) level showed additional improvement over the .3%, and the .7% (weight) formulation was completely free of rust (Figure 4).

At this juncture, it was suggested by Southwest Research Institute that we test the formulation in the procedure as noted in the MIL-P-46002. It was indicated that our material at .3% to .7% was not expected to perform in this test situation as would a qualified MIL-P-46002 at 6% to 8% (weight) concentration of the VSI inhibitor. However, it was suggested that there should be some improvement over the performance of the neat 21260. The test was performed and the results indicated (Figure 5). It can be seen that the increment of improvement even at .3% over the neat 21260 is dramatic. Four grams of test oil were used, which corresponds to the requirements for Grade 2 of MIL-P-46002. However, when we ran this test using 6 grams of oil, the results are close to passing the vapor phase test of MIL-P-46002. Considering the difference in viscosity of the Grade 2 of MIL-P-46002 and the Grade 30 of 21260, I suggest the correct sample size for the 21260 should be about 7 grams. (It cannot be seen on Figure 5, but there are a number of very tiny dots of rust on the 6-gram sample coupon).

3C. BENCH TESTS

All of the bench tests have been completed as required, with the exception of the humidity cabinet, which is in progress and will be reported at a later date. As can be seen from the results sheet, all of the tests are within the parameters of MIL-L-21260, with the exception of the foaming, at the .5% and .7% concentation level (Chart No. 3).

4. CONCLUSIONS

1. Incorporating specific vapor-space corrosion (VSI) inhibitors in operational motor oils has been shown by laboratory experiments to be feasible.

2. It has been demonstrated that a concentration of VSI component can be used in a range of .3% to .7% (weight) in a formulated engine oil.

3. The formulation containing .3% of VSI component met all of the requirments for MIL-L-21260 C, Grade 30.

4. The ASTM test apparatus permits testing of the inhibited oil under conditions approximating field conditions.

5. The ASTM VSI apparatus can determine the relative effectiveness of the VSI component in the formulated oil.

6. Large quantities of inhibited oil may be readily formulated by blending the VSI component into the base oil.

ADDENDUM

3.D. CONTINUING RESULTS AND DISCUSSION.

Some preservation procedures require that the fuel system be flushed with MIL-L-21260, Grade 10. For this reason, it is important that the VSI additive package be the same or compatible with the VSI additive used in the engine crankcase oil. It was found by laboratory tests that the VSI component used in the MIL-L-21260, Grade 30 submission precipitated when used in the Grade 10 oil. It is also indicated on the Data Sheet (Chart 3, Appendix A) that there is a substantial increase of the foaming characteristics of the .3% inhibited Grade 30 oil, as compared to the neat Grade 30 oil.

A different additive package was then selected which laboratory tests indicated was equally soluble in Grade 10 oil, as well as Grade 30 oil. This product has been qualified for use in MIL-L-23310 and MIL-L-85062. There are other advantages for use of this VSI inhibitor as noted on our Data Sheet (Chart 4, Appendix A). It provided a considerable improvement in the foaming characteristics over the neat Grade 30 oil. As to the Humidity Cabinet test, MIL-L-21260, paragraph 4.6.1, our test results indicate a failure after seven (7) days in the neat Grade 10 and Grade 30, as well as in the test oils.

While working with the Grade 10 oil, we found that the test procedure as noted (page 2, paragraph 2 and 3.B), would have to be modified, in that the control test coupon did not show any significant rusting, as compared to the test samples. Further investigation revealed that the test coupons used in this case were made of 1018 steel instead of preferred 1020 steel. We then proceeded to modify the test methodology by the following: The test is run for sixteen (16) hours at 130°F., then to increase the water to 5 ml. from 2 ml. Then, to increase the residence time from three (3) to six (6) hours. This modified test procedure was then used for both the Grade 30 and Grade 10 oils with satisfactory results.

5. RECOMMENDATIONS

1. The completed VSI research suggests that other classes of chemical compounds could also be effective VSIs.

2. Additional work should be performed to evaluate various isomers of the VSI component as to their effectiveness.

3. Testing should be performed to determine any effect of VSI oils on non-ferrous metals, plastics and elastomers.

4. Further research is needed to determine the life of the VSI component in the formulated oil under static and operating conditions.

5. Testing should be started to evaluate and standardize optimum sample size and temperature parameters for different viscosities of oil.

6. Further studies should be made to determine and establish quantitative requirements and establish depletion parameters.

This is to express my appreciation to the

FOUNDATION FOR APPLIED SCIENCE AND TECHNOLOGY

of the

UNIVERSITY OF PITSBURGH

and especially to

DR. HAROLD E. SWIFT, ACTING PRESIDENT

His advice and counsel have been invaluable.

Maurice S. Bateman, President
Ronco Laboratories, Inc.

1. APPARATUS REAGENTS AND MATERIALS

A. Water bath capable of maintaining $54 \pm 1^{\circ}$ C.

B. Circulating system capable of maintaining a water temperature of $21 \pm 1^{\circ}$ C at both inlet and outlet of specimen holder.

C. Test assembly, as shown in Chart No. 5.

D. Adapter, threaded 3/8 x UNF, for holding corrosion coupon in chuck.

E. Abrasive cloth, Aluminum Oxide, 280 grit.

2. PREPARATION OF APPARATUS

A. Wash glassware in hot water detergent solution and rinse with tap water. Clean with chromic acid cleaning solution; rinse with tap water, then with distilled water. Dry in an oven and cool to room temperature.

B. Wash teflon sleeve, seal and cup in hot water-detergent solution; rinse with tap water, then distilled water, and allow to dry.

C. Mount the metal corrosion specimen holder in a drill chuck and rotate. Prepare a fresh metal surface by applying the Aluminum Oxide paper to the rotating specimen. Finally, wipe the specimen with lintless material and immerse in iso-octane until ready to use.

3. PROCEDURE

A. Stopper the flask and place it in the bath, which is at the test temperature of 54° C.

B. Mount the insulating sleeve on the specimen holder, which is at the test temperature of 21° C.

C. Remove the specimen from the iso-octane and air dry. Install the washer and mount the specimen in the holder.

D. After shaking the sample, place 2 grams of the test oil in the sample cup and mount it on the teflon sleeve.

E. Place the specimen assembly in the flask, as shown in Figures 2 and 3.

F. At the end of an induction period of 16 hours, add 2 ml. of distilled water to the flask.

G. Continue the test for 3 hours. Remove the specimen and describe its appearance.

Note: Use a small amount of stopcock grease on the neck of the flask to prevent freezing of the teflon to the next of the flask.

CK

CHEMICAL	SEVERE RUST	MODERATE RUST	SOME RUST	PASS
1. iso-hexenyl succinic anhydride-cocoamine			X	
2. iso-hexenyl succinic anhydride-dicyclohexylamine	X			
3. iso-hexenyl succinic anhydride-cyclohexylamine		X		
4. iso-hexenyl succinic anhydride-diisobutylamine	X			
5. iso-hexenyl succinic anhydride-di-n-butylamine			X	
6. di-2-ethylhexyl phosphoric acid-dicyclohexylamine			X	
7. di-2-ethylhexyl phosphoric acid-cocoamine			X	
8. di-2-ethylhexyl phosphoric acid-diisobutylamine		X		
9. di-2-ethylhexyl phosphoric acid-cyclohexylamine		X		
10. oleic acid-tris dioxa heptyl amine		X		
11. oleic acid-cocoamine	X			
12. oleic acid-cyclohexlamine		X		
13. oleic acid-dicyclohexylamine	X			
14. oleic acid-diisobutylamine		X		
15. oleic acid-di-n-butylamine		X		
16. n-hexenyl succinic anhydride-dicyclohexylamine		X		
17. n-hexenyl succinic anhydride-cyclohexylamine		X		
18. n-hexenyl succinic anhydride-di-n-butylamine		X		
19. n-hexenyl succinic anhydride-diisobutylamine		X		
20. n-hexenyl succinic anhydride-tris-dioxa heptyl amine		X		

CHART 1

CHEMICAL	.5%	1%	PASS
1. iso-hexenyl succinic anhydride-cocoamine	Moderate Rust	Some Rust	No
2. iso-hexenyl succinic anhydride-dicyclohexylamine	Severe Rust	Moderate Rust	No
3. iso hexenyl succinic anhydride-cyclohexylamine	Moderate Rust	Moderate Rust	No
4. iso-hexenyl succinic anhydride-diisobutylamine	Severe Rust	Severe Rust	No
5. iso-hexenyl succinic anhydride-di-n-butylamine	Moderate Rust	Moderate Rust	No
6. di-2-ethylhexyl phosphoric acid-dicyclohexylamine	Moderate Rust	Some Rust	No
7. di-2-ethylhexyl phosphoric acid cocoamine	Some Rust	Some Rust	No
8. di-2-ehtylhexyl phosphoric acid-diisobutylamine	Moderate Rust	Moderate Rust	No
9. di-2-ethylhexyl phosphoric acid cyclohexylamine	Moderate Rust	Moderate Rust	No
10. oleic acid-tris dioxa heptyl amine	Moderate Rust	Moderate Rust	No
11. oleic acid-cocoamine	Severe Rust	Moderate Rust	
12. oleic acid-cyclohexylamine	Moderate Rust	Moderate Rust	No
13. oleic acid-dicyclohexylamine	Severe Rust	Moderate Rust	No
14. oleic acid-diisobutylamine	Moderate Rust	Moderate Rust	No
15. oleic acid-di-n-butylamine	Moderate Rust	Moderate Rust	No
16. n-hexenyl succinic acid anhydride-dicyclohexyla,one	Moderate Rust	Moderate Rust	No
17. n-hexenyl succinic acid anhydride-cyclohexylamine	Moderate Rust	Moderate Rust	No
18. n-hexenyl succinic anhydride-di-n-butylamine	Moderate Rust	Moderate Rust	No
19. n-hexenyl succinic anhydride-diisobutylamine	Moderate Rust	Moderate Rust	No
20. n-hexenyl succinic anhydride-tris-dioxa heptyl amine	Moderate Rust	Moderate Rust	No
21. n-pentenyl succinic anhydride-dicyclohexylamine	Moderate Rust	Moderate Rust	No
22. n-pentenyl succinic anhydride-cyclohexylamine	Moderate Rust	Moderate Rust	No
23. n-pentenyl succinic anhydride-diisobutylamine	Moderate Rust	Moderate Rust	No
24. n-pentenyl succinic anhydride-cocoamine	Severe Rust	Severe Rust	No
25. n.pentenyl succinic anhydride-di-n-butylamine	Severe Rust	Severe Rust	No

Severe Rust - Rust over entire coupon
Moderate Rust - Rust around part or all of lower half of coupon

CHART 2

TEST	NEAT 21260, Grade 30	21260 with .3% inhibitor	21260 with .5% Inh.	21260 with .7% Inh.
Vis. @ 40 C. Cs.	93.41	97.76	99.59	103.38
Vis. @ 100 C. Cs.	11.14	11.2	11.2	11.33
Vis. @ -18 C. Extrap.	10,000	11,000	12,000	15,000
VI	110	108.3	106.3	103.69
Flash Point (COC)	238 C.	232 C.	232 C.	224 C.
Pour Point	-37 C.	-37 C.	-37 C.	-37 C.
Gravity API	27.4	27.3	27.3	27.4
Sulfur %	.69	.66	.66	.68
Humidity Cabinet	In Progress	In Progress	In Progress	In Progress
Carbon Res. Ramsbottom	1.03	1.07	1.07	1.07
Total Base #	6.2	7.0	7.2	7.6
Neut # Total Acid	1.6	1.9	2.4	2.7
Sulfated Ash %	.87	.86	.87	.87
Foam 5 Min Blow Ml Sec. 1 2 3	 5 20 10	 20 330 15	 190 580 225	 320 600 410
Foam 10 Min Blow Ml Seq. 1 2 3	 0 0 0	 0 0 0	 70 150 130	 230 300 290
Additive Element % P	.10	.10	.10	.10
Trace Metals % Ba Ca Na Zn Mg	<0.001 0.06 0.07 0.15 0.04	<0.001 0.06 0.07 0.15 0.04	<0.001 0.06 0.07 0.15 0.04	<0.001 0.06 0.06 0.15 0.04
Salt Water Immersion	Pass	Pass	Pass	Pass

Ronco Labs., Inc.

CHART 3

	MIL-L-21260	VADEN-500 G		VADEN-500 G
Test	Neat Grade 30	Gr. 30, .5%	Neat Grade 10	Gr. 10, .5%
Vis. @ 40 C. Cs.	93.41 Cs.	89.32 Cs.	42.2 Cs.	36.9 Cs.
Vis. @ 100 C. Cs.	11.14 Cs.	11.0 Cs,	6.69 Cs.	6.2 Cs.
Vis. @ -18 C. Extrap.	10,000 Cs.	10,000 Cs.	2,500 Cs.	2,500 Cs.
VI	110	114.9	112	124.8
Flash Point (COC) C	238	227	215	213
Pour Point C	-32	-32	-32	-32
Gravity API	27.4	27.1	29	28.8
Sulfur %	.69	.68	.98	1.05
Humidity Cabinet	Fail 7 Days	Fail 7 Days	Fail 7 Days	Fail 7 Days
Carbon Res. Ramsbottom	1.03	1.01	.084	.89
Total Base #	6.2	7.5		7.0
Neut # Total Acid	1.6	1.4		1.3
Sulfated Ash %	.87	.80	.89	.78
Foam 5 Min Blow Ml Seq. 1 2 3	 5 20 10	 5 10 5		 10 30 5
Foam 10 Min Blow Ml Seq. 1 2 3	 0 0 0	 0 0 0		 0 0 0
Additive Element % P	.10	.098	.114	.091
Trace Metals % Ba Ca Na Zn Mg	< 0.001 0.06 0.07 0.15 0.04	<1 ppm .062 .062 .15 .038	 .067 .182 .051	3 ppm .060 .067 .14 .037
Salt Water Immersion	Pass	Pass	Pass	Pass
Heat Test P715(A) Precip.		24 Hrs. 48 Hrs, NONE		24 Hrs 48 Hrs. NONE

Ronco Labs., Inc.

21260C, Grade 30 Qual. # MPL-154 Supplied by Valvoline Oil Co., Freedom, Pa.

21260C, Grade 10 Valvoline Oil Co., Freedom, Pa. Supplied by Southwest Research Institute.

CHART 4

APPENDIX B

ABSTRACT OF

PATENT AND LITERATURE SEARCH

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ABSTRACT OF PATENT
AND LITERATURE SEARCH
SUBMITTED TO THE
SOUTHWEST RESEARCH INSTITUTE

PATENT ABSTRACTS FROM 1950 THROUGH MAY 1985

Samples of the search of U.S. patent data base on Lubricant Corrosion Inhibitors revealed that almost all of the patent activity was of non-volatile contact inhibitors, consisting of lubricating compositions for fuels, cutting and grinding fluids, colling fluids for motors, etc. Ronco Laboratories patents for volatile corrosion inhibitors in both solid state and lubricants were issued during this period.

The level of patent activity, while latent in the United States, is, and has been active in East Europe and Japan in the area of volatile corrosion inhibitors. All of the available recent literature on this topic has been produced in Poland, the U.S.S.R., Romaina, Iran and Japan.

EXAMPLE OF SEARCH OF A CYCLOHEXYLAMINE COMPOUND

The search topic was "Octanamide, N, N-bis (cyclohexyl). The objective was to (1) identify a CAS registry number for this substance, and (2) to identify abstracts and references which would describe its preparation and/or properties.

A consultant to OEM conducted a thorough search of this subject compound and found that this subject substance had never been cited in any literature abstracted by CAS since 1947. The procedure for this activity was described which involved both electronic and manual searches. The result was not successful as no match was found in the period from 1947 to 1966.

ANTICORROSIVE SERVICE BY L. KAMIONSKII
Source: Nauchno-Tekhnicheskiye Obshchestva SSSR,
No. 6, pp. 11-13, 1968, USSR. (Translated for FSTC by Techtran Corp)

This article was a summary of methods and means of addressing corrosion in metals. The initial discussion centered around the interests and efforts of the USSR to produce steel with corrosioninhibiting properties through the introduction of nickel alloy, i.e., chrome-nickel steel with a low percentage of carbon (0.03%) which are properted to be stable against corrosive cracking.

On the assumption that the measures for corrosion protection are more effective at the plants where machinery, parts, etc., are produced, accelerated

Manufacturing and Repairing Electrical and Mechanical Subassemblies

methods for processing rolled iron on highly productive equipment--electrolytic tinplating of sheet iron instead of hot plating, passivating of the hot-galvanized band, parerizing, light processing with chromium and lacquering, electrolytic sourcing and other methods for preparing the surface of rolled iron for the application of protective coatings were recommended.

In contrast to processing products by the piece, the use of a method promoted by the All Union Scientific Research, Planning and Design Institute of Metallurgical Machinery gave rise to greater efficiency with approximately twice the level of resistance to corrosion with a simultaneous reduction in the thickness of the hot zinc coating of gas and water pipes to a minimum of 20 microns.

Various applications, such as paint and varnish coatings, various systhetic film-like compounds, impervious to steam, moisture and gas, highly adhesive to metal and having a significant mechanical stability were also discussed in detail as means to inhibiting corrosion activity.

Reference was made to the increase in use and interest of volatile inhibitors, as well as the introduction of same to pain and varnish coatings, protective lubricants and oils. The use of VCI treated paper and packaging reflected recognition of the effectiveness and cost efficiency of such VCIs.

Without a comprehensive anticorrosion service, little progress, it was suggested, might remain unrealized. Also proposed was the formation of several anti-corrosion productive organizations as well as the creation of an ALL Union association to coordinate this research.

Plastic lubricants were recommended; PVK, GOI-54p,Skhk were plastic lubricants developed by the Moscow Institute for petroleum, chemical and gas industries. The properties and uses were discussed in detail.

Enameled pipes, involving the application of silicate enamels through electric heating was also described. Such pipes were used in refrigerator ships, tankers and in ship seawater lines. The equipment displayed good corrosion resistance and satisfactory mechanical toughness to impact, vibration, bending and other loads.

In conclusion, the interest and development of corrosion inhibiting applications and products were probably paralleling development in the United States.

SURVEY OF VAPOR CORROSION IN HIBITORS by D.W. SLOCUM
Source: University of Pittsburgh NASA Industrial Applications Center.

The purpose of this paper was to establish the need to develop Vapor Corrosion Inhibitor products for operational uses. It was to be the preliminary document as part of a comprehensive product research and development program to be launched as a joint effort by OEM INDUSTRIAL CORPORATION and RONCO LABORATORIES, INC.

The benefits of VCI protection were delineated; general properties of VCI formulations were described. The descriptions of said formulations did not include those of Ronco Laboratories.

The product usage in the current, or rather, existing formulations, is limited to storage and shipping, both in the industrial and military arenas.

I.L. Rozenfeld, a prominent researcher in this field (deceased) was identfied and the range of his findings was discussed.

Mr. Slocum expressed concern about various environmentally unacceptable ingredients. However, it was acknowledged that some VCIs are environmentally acceptable.

CONCLUSIONS

After extensive literature and patent searches, one can only assume that the development of Vapor Corrosion Inhibitor products is a step or two behind the rest of the world. It could be due to the fact that the importance of corrosion prevention is appreciated by disparate groups in both the public and private sector and is approached from markedly different angles.

We, too, feel that a comprehensive research approach is necessary and that the industry should develop standards and better testing methodology. It is also believed that the domestic research program should be accelerated.

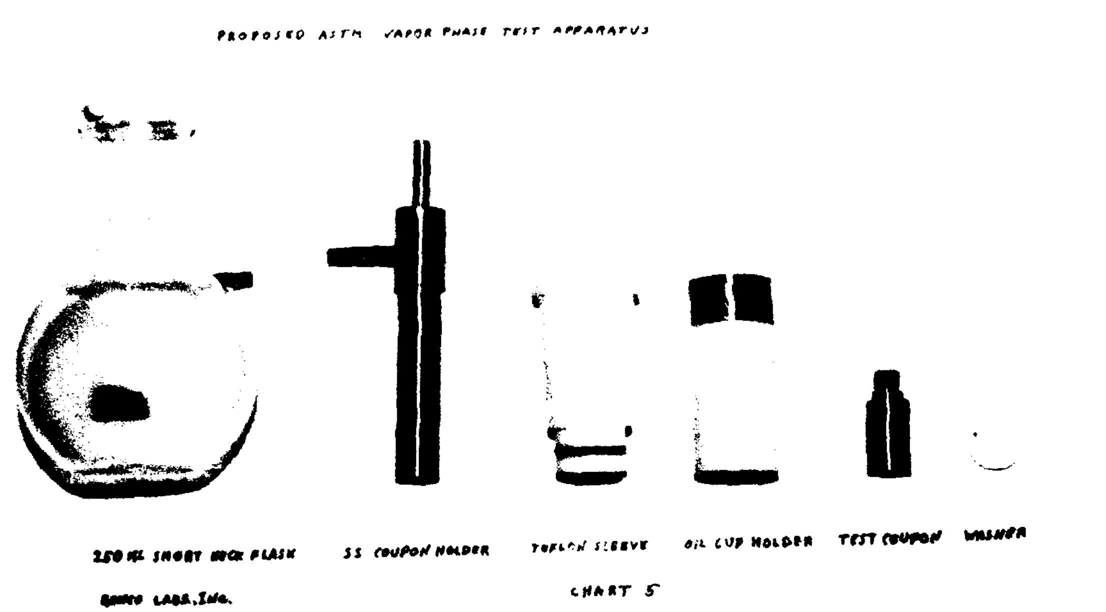


Figure 1

Figure 2

Figure 3

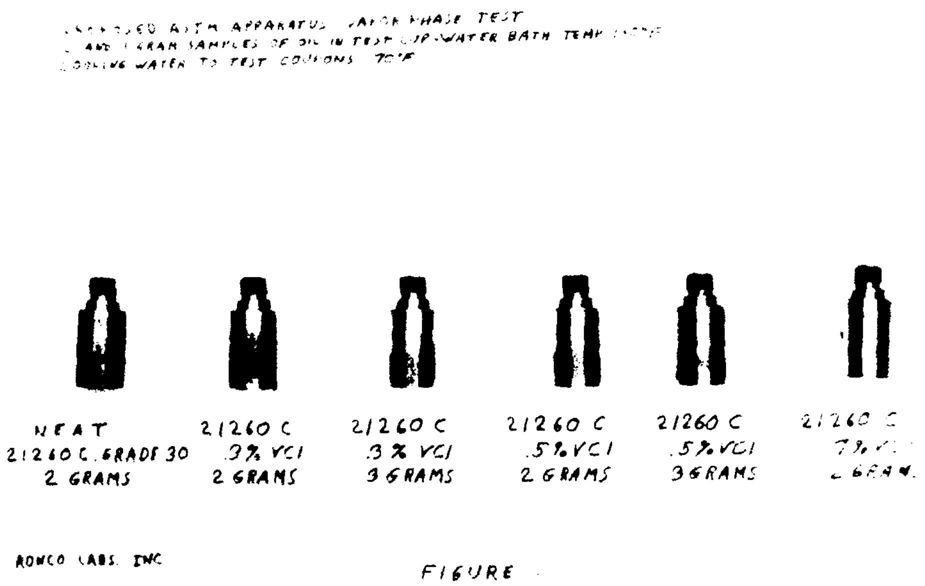


Figure 4

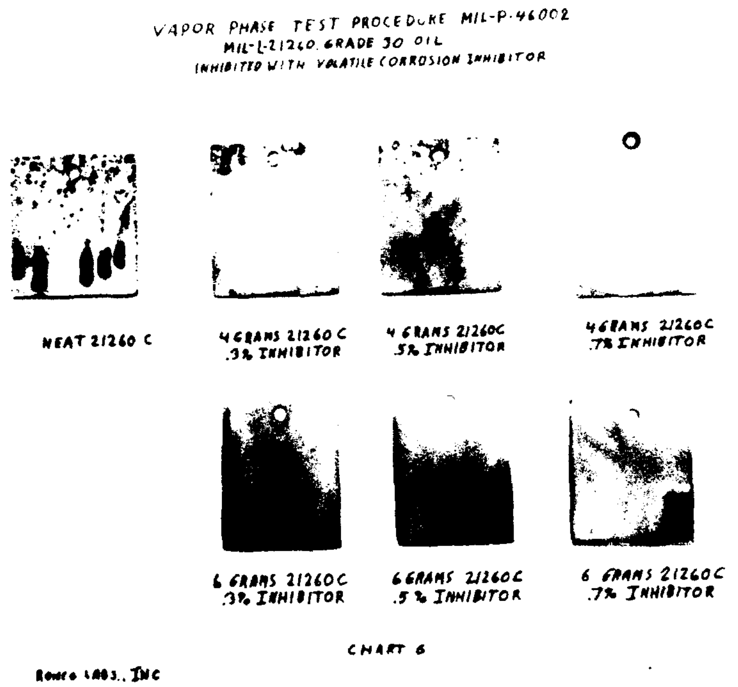


Figure 5

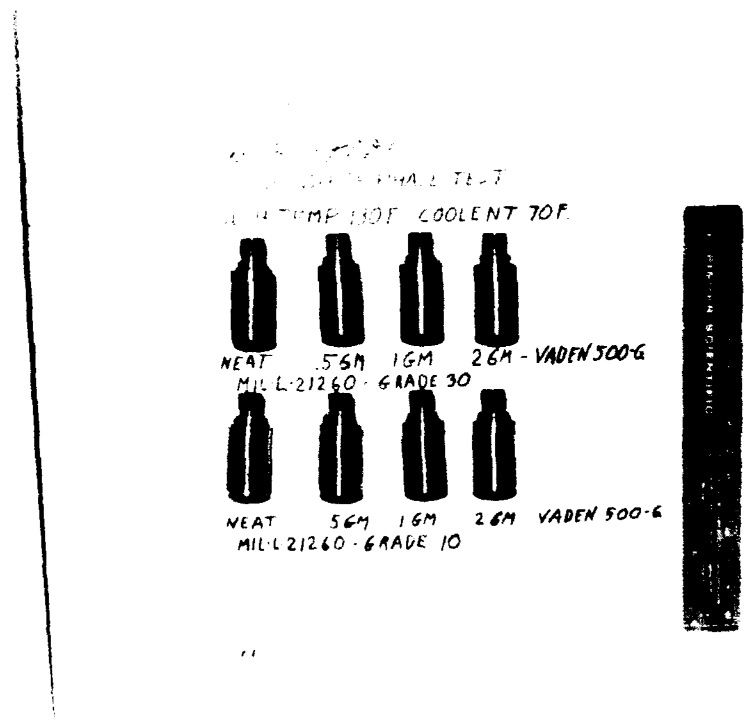


Figure 6

APPENDIX B

Caterpillar 1H2 Engine Test Reports

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
ENGINES, FUELS AND LUBRICANTS

CATERPILLAR 1-H2 LUBRICANT EVALUATION

Conducted for

U.S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY

on Test Oil

AL-15052

63A Single Cylinder Engine Tests
7.0 Test Certification
1H2 TEST STAND CALIBRATION STATEMENT

Test No. 17-86 for evaluation of oil AL-15052 has, in my opinion been conducted in a valid manner in accordance to STP 509A Part II and appropriate amendments by the information letter system. The detailed remarks provided in this report describe the deviations and any unusual features associated with this test.

The test stand has been calibrated in accordance to the requirements specified in ASTM STP 509A Part II and the appropriate amendments through the information letter system.

SwRI

Mark R. Sutherland
Research Engineer

July 4, 1986

This Caterpillar 1-H2 evaluation was conducted to determine the effect of the lubricant on ring sticking, wear, and accumulation of deposits.

The evaluation was run in accordance with the Federal Test Method 346 (1-H2) dated February 15, 1977, with the indicated modifications, if any. The operating conditions were those specified for this supercharged diesel test, and a fuel of 0.35% minimum sulfur content was used.

Tabulated on the following pages is a summary of the results at the conclusion of the 480 hour procedure. Piston deposit ratings and tabulations and a graph of the test operating conditions are included.

Figure 25

1.0 TEST IDENTIFICATION

FTMS 791, Method 346 1-H2	Laboratory LO-030528 SwRI	Oil Code AL-15052	
Stand No. 17	Stand Run No. 86	Engine No. 1A300	Fuel (Mfr.-Batch) Howell Hydrocarbons 86-3
Date Started 06/13/86	Date Completed 07/04/86	Test Hours 480	

2.0 REFERENCE TESTS

STAND LAST REFERENCE		Engine No.	Date Completed	Oil I.D.
Stand No.	Stand Run No.	1A300	04/26/86	SR-0211(G) CMIR-7519
17	83A	Test Rating WTD= 155.7 ,TGF= 55.0%		Industry Average WTD= 220.1 ,TGF= 56.6%

LAB LAST REFERENCE		Engine No.	Date Completed	Oil I.D.
Stand No.	Stand Run No.	1A837	06/13/86	SR-0196(G) CMIR-7135
05	34	Test Rating WTD= 110.8 ,TGF= 18.0%		Industry Average WTD= 134.0 ,TGF= 26.1%

3.0 EVALUATION OF ENGINE PARTS

3.1 Piston Deposits (Groove Backs and Lands)

	Dep. Type	Dep. Fct.	Grooves No. 1 A,%	Grooves No. 1 Dem.	Grooves No. 2 A,%	Grooves No. 2 Dem.	Grooves No. 3 A,%	Grooves No. 3 Dem.	Grooves No. 4 A,%	Grooves No. 4 Dem.	Lands No. 2 A,%	Lands No. 2 Dem.	Lands No. 3 A,%	Lands No. 3 Dem.	Lands No. 4 A,%	Lands No. 4 Dem.
C	HC	1.000	3	3.00												
A	MHC	0.750														
R	MC	0.500	24	12.00												
B	LC	0.250	54	13.50	46	11.50					22	5.50	1	0.25	5	1.25
O	VLC	0.150														
N	Total		81	28.50	46	11.50					22	5.50	1	0.25	5	1.25
L	BL	0.100	12	1.200	7	0.700					18	1.800	12	1.200	13	1.300
A	DBRL	0.075	2	0.150	4	0.300					1	0.075	18	1.350	21	1.575
C	AL	0.050			1	0.050					1	0.050	8	0.400	20	1.000
Q	LAL	0.025	5	0.125	11	0.275	37	0.925			14	0.350	32	0.800	27	0.675
U	VLAL	0.010			29	0.290	39	0.390			30	0.300	29	0.290	11	0.110
E	RL	0.000														
R	Total		19	1.475	52	1.615	76	1.315			64	2.575	99	4.040	92	4.660
Clean					2		24		100		14				3	
Rating				29.975		13.115		1.315		0.000		8.075		4.290		5.910
Location Factor				1		10		35		70		3.5		20		35
Weighted Rating				29.975		131.150		46.025		0.000		28.263		85.800		206.850
Total Weighted Demerit				528.1												
Top Groove Filling, %				19												

RATER: AB

Figure 25 (Cont.)

TEST NO. 17-86 OIL CODE AL-15052 DATE 07/04/86

3.2 SUPPLEMENTAL PISTON DEPOSITS (GROOVE SIDES & RINGS)

DEPOSIT TYPE			CARBON			LACQUER					
			HC	MC	LC	BL	DBRL	AL	LAL	VLAL	RL
SKIRT											
UN-CROWN									45	55	
LINER ABOVE RING TRAVEL											
PISTON CROWN					33						
GROOVE TOP AND BOTTOM	1	T							100		
		B							100		
	2	T				20			40		
		B							40		
	3	T							30		
		B							40		
	4	T						20	35		
		B							30		
TOP BOTTOM & BACK OF RINGS	1	T							100		
		B							100		
		BK			100						
	2	T							100		
		B							100		
		BK			100						
	3	T							100		
		B							100		
		BK							100		
	4	T							100		
		B							100		
		BK							100		

3.3 ADDITIONAL DEPOSIT & CONDITION RATINGS

A. Piston Crown Scuffing (Nature and Quantity)

Numerous fine vertical line cuttings

B. Amount and Nature of Deposits on Oil Ring Slots

Nil

C. Piston Skirt Condition (Not Including Deposits)

Polished areas normal with few fine to coarse vertical lines

D. Liner Condition

Normal

62a SINGLE CYLINDER ENGINE TESTS CATERPILLAR 1-H2

Figure 25 (Cont.)

TEST NO. 17-86 OIL CODE AL-15052 DATE 07/04/86

4.0 OPERATIONAL AND MEASUREMENT SUMMARY

OPERATING CONDITION		MIN	MAX	AVG
Engine Speed,RPM	1800±10	1795	1805	1801
Engine Load				
BHP	Approx.33	31.9	33.4	32.7
BTU Input/Min	4950±50	4933	4962	4949
Humidity,Grains/Pound	125±5	116	132	124
Temperature,°F				
Coolant Jacket Outlet	160±5	159	161	160
Coolant Jacket Inlet	Record	150	153	151
Coolant Jacket ΔT	Record	7	9	8
Oil to Bearings	180±5	178	181	180
Inlet Air	170±5	168	171	170
Exhaust	1050±50	1029	1079	1063
Oil Cooler Inlet	Record	----	----	----
Fuel	Record	----	----	----
Pressures				
Oil to Bearings,PSI	32 Max.	28.3	30.4	29.2
Oil to Jet,PSI	24±2	23.2	24.6	23.9
Inlet Air in.Hg.(abs)	40±0.3	39.8	40.1	39.9
Exh.Back Press.,in.H_2O	6±6	3.0	3.0	3.0
Fuel(On Test),PSI	20±2	18.0	21.0	19.1
Fuel(Rate Meas),PSI	20±2	18.0	21.0	19.1
C'Case Vacuum,in.H_2O	1.0±0.5	1.0	1.0	1.0
Blowby,CFH	Record	11.40	18.00	13.75
Oil Consumption,#/BHP-HR	Max.			
0-120	0.004			0.00124
120-240	0.004			0.00131
240-360	0.004			0.00123
360-480	0.004			0.00122
0-480				0.00125
Coolant Flow,GPM	15.3±1	14.68	15.47	15.08
Air Fuel Ratio	23.5±1:1	22.6:1	23.1:1	22.9:1
Compression Ratio	16.4±0.5	16.4:1	16.4:1	16.4:1

MEASUREMENTS

RING GAP INCREASE

NO.1	NO.2	NO.3	NO.4
0.002	0.001	0.001	0.001

RING SIDE CLEARANCE

	Before Test		After Test	
	MIN	MAX	MIN	MAX
1	0.0045	0.0050	0.0045	0.0050
2	0.0035	0.0040	0.0035	0.0040
3	0.0035	0.0040	0.0035	0.0040
4	0.0015	0.0020	0.0015	0.0020

LINER WEAR STEP

Longitudinal	Transverse
0.0003	0.0005

CONDITIONS OF RING

FACE Normal

SHARPNESS Normal

NO. TIGHT None

NO. STUCK None

Fuel Gravity: 0 Hours 34.9, 480 Hours 34.9.
D287

REMARKS:

Figure 25 (Cont.)

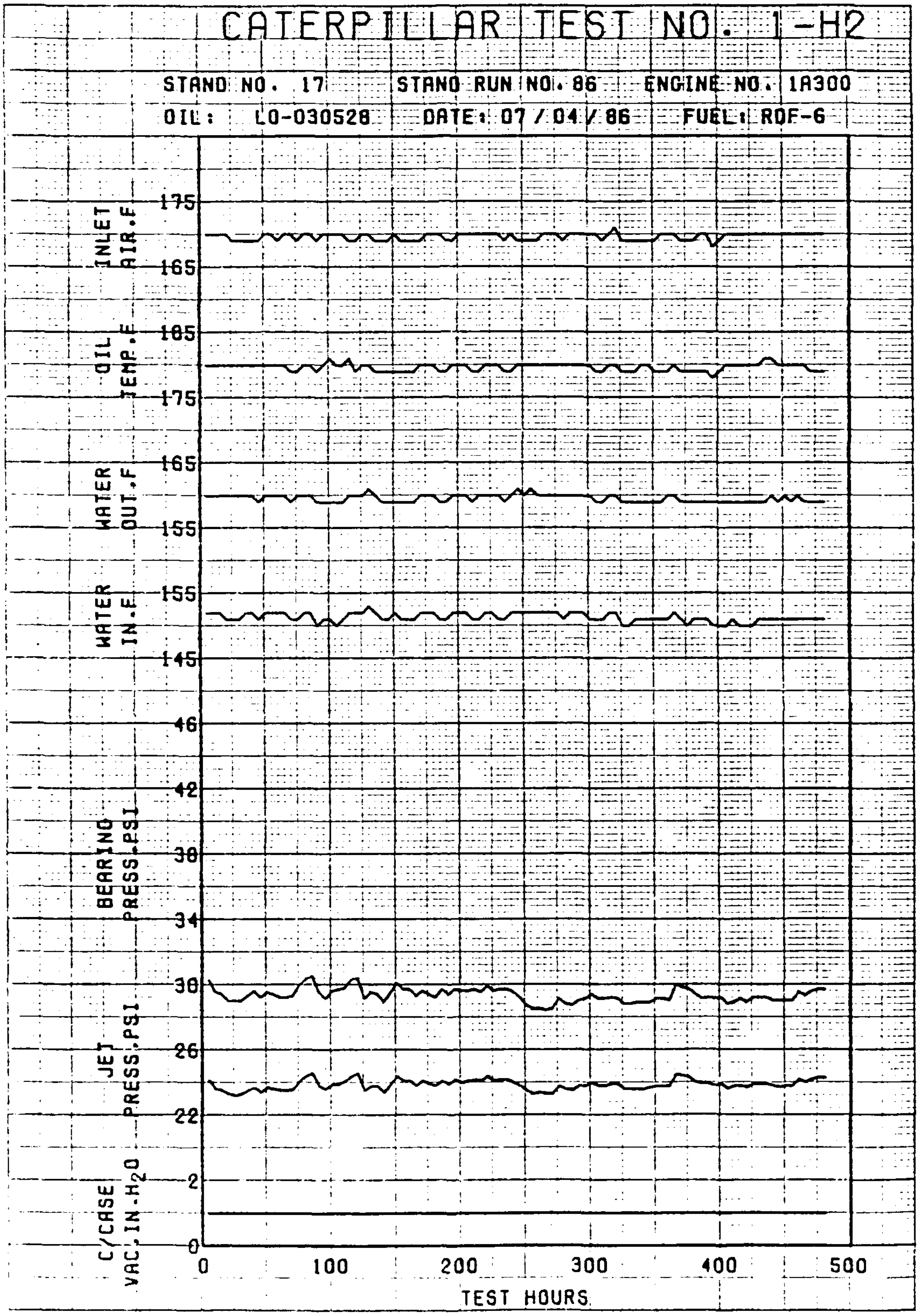
TEST NO. 17-86 OIL CODE AL-15052 DATE 07/04/86

5.0 TEST LOST TIME AND INSPECTION

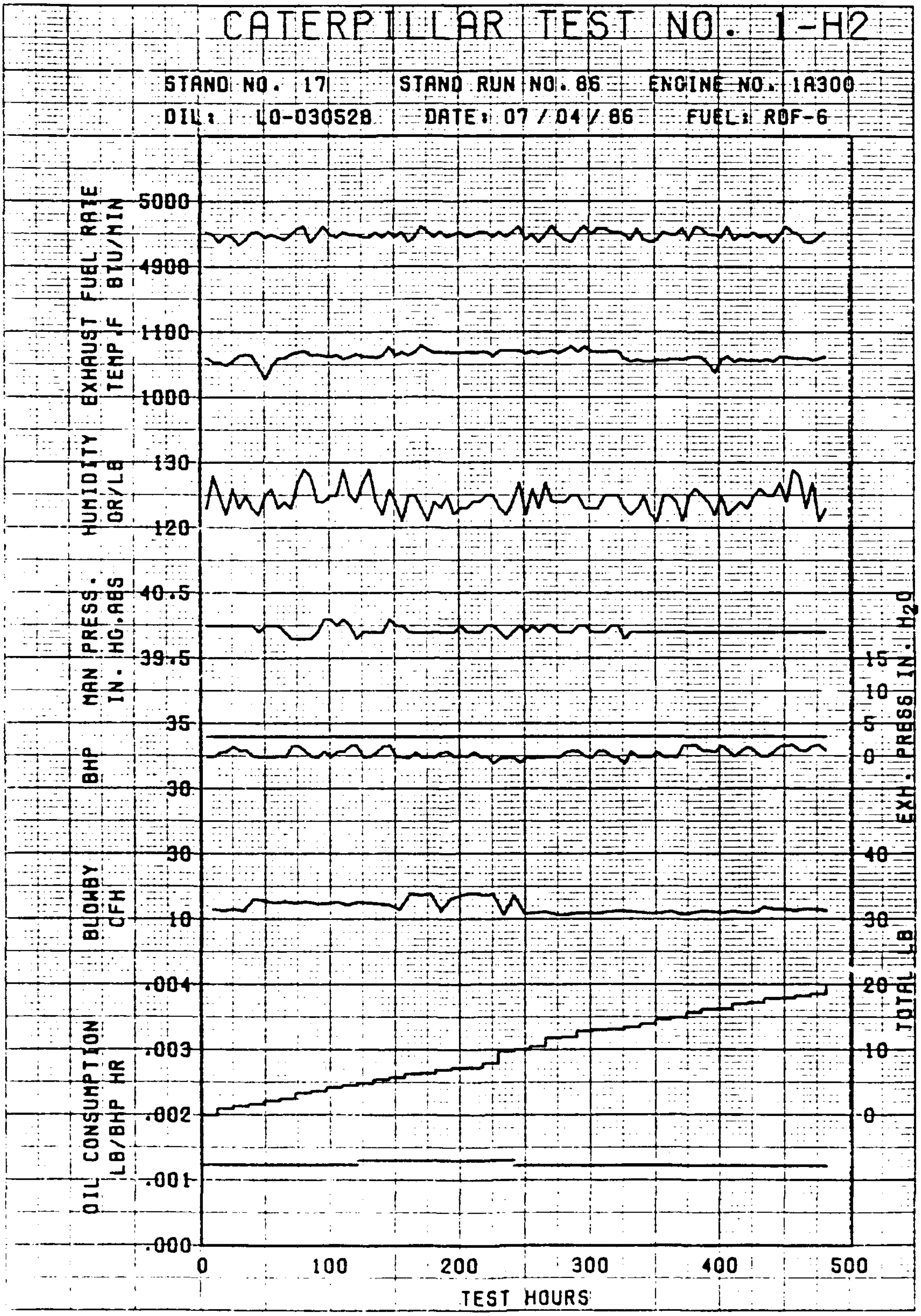
TEST HOURS	DATE	TIME DOWN	REMARKS
85	06/17/86	1h 33m	Water leak at crossover pipe. Replaced gasket.
120	06/18/86	1h 54m	Oil change.
240	06/23/86	2h 18m	Oil change.
360	06/29/86	1h 54m	Oil change.
365	06/29/86	1h 18m	Replaced oil line on fuel cam housing.
			Note: If no lost time state this fact.
			INSPECTION None

6.0 TEST MODIFICATIONS AND COMMENTS

Humidity - 116 grains at 41 hours.
Humidity - 117 grains at 114 hours.
Humidity - 119 grains at 197 hours.
Humidity - 132 grains at 338 hours.
Humidity - 118 grains at 391 hours.
Humidity - 117 grains at 466 hours.
Humidity - 118 grains at 471 hours.



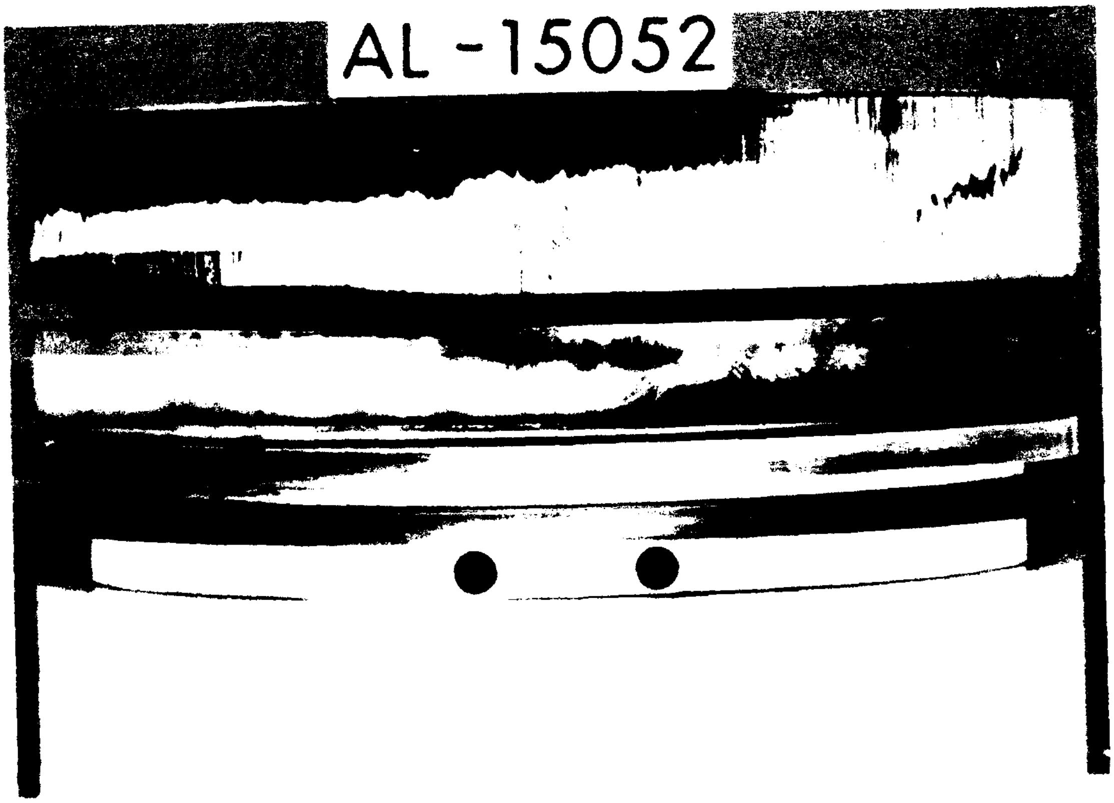
CATERPILLAR TEST NO. 1-H2
STAND NO. 17
STAND RUN NO. 86
ENGINE NO. 1A300
OIL: LO-030528
DATE: 07 / 04 / 86
FUEL: RDF-6
INLET AIR.F
OIL TEMP.F
WATER OUT.F
WATER IN.F
BEARING PRESS.PSI
JET PRESS.PSI
C/CASE VAC.IN.H_2O
175
165
185
175
165
155
155
145
46
42
38
34
30
26
22
2
0
0
100
200
300
400
500
TEST HOURS


CATERPILLAR TEST NO. 1-H2
STAND NO. 17
STAND RUN NO. 86
ENGINE NO. 1A300
OIL: LO-030528
DATE: 07 / 04 / 86
FUEL: RDF-6
FUEL RATE BTU/MIN
5000
4900
EXHAUST TEMP.F
1100
1000
HUMIDITY GR/LB
130
120
MAN PRESS. IN. HG.ABS
40.5
39.5
BHP
35
30
BLOWBY CFH
30
10
OIL CONSUMPTION LB/BHP HR
.004
.003
.002
.001
.000
0
100
200
300
400
500
TEST HOURS
EXH. PRESS IN. H_2O
15
10
5
0
TOTAL LB
40
30
20
10
0

FUEL INSPECTION
HOWELL HYDROCARBONS LOW SULFUR DIESEL FUEL - BATCH 86-3

Gravity, °API	34.9
Flash Point, °F	178
Water and Sediment, % v	<0.05
Pour Point, °F	+ 20
Carbon Residue, % wt.	0.10
Ash, % wt.	<.001
Distillation	
IBP	390
10%	462
50%	520
90%	604
End Point	658
Recovery, %	---
Kinematic Viscosity, Centistokes @ 100°F	3.21
Sulfur, % wt.	0.41
Corrosion	1A
Neutralization No. TAN	0.06
Centane Number Cal.	48.0


AL-15052


AL-15052

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
ENGINES, FUELS AND LUBRICANTS

CATERPILLAR 1-H2 LUBRICANT EVALUATION

Conducted for

FORT BELVOIR FUELS & LUBRICANTS
RESEARCH FACILITY

on Test Oil

AL-15293L

63A Single Cylinder Engine Tests
7.0 Test Certification
1H2 TEST STAND CALIBRATION STATEMENT

Test No. 16-96 for evaluation of oil AL-15293L has, in my opinion been conducted in a valid manner in accordance to STP 509A Part II and appropriate amendments by the information letter system. The detailed remarks provided in this report describe the deviations and any unusual features associated with this test.

The test stand has been calibrated in accordance to the requirements specified in ASTM STP 509A Part II and the appropriate amendments through the information letter system.

SwRI

Mark R. Sutherland
Research Engineer

August 13, 1986

This Caterpillar 1-H2 evaluation was conducted to determine the effect of the lubricant on ring sticking, wear, and accumulation of deposits.

The evaluation was run in accordance with the Federal Test Method 346 (1-H2) dated February 15, 1977, with the indicated modifications, if any. The operating conditions were those specified for this supercharged diesel test, and a fuel of 0.35% minimum sulfur content was used.

Tabulated on the following pages is a summary of the results at the conclusion of the 480 hour procedure. Piston deposit ratings and tabulations and a graph of the test operating conditions are included.

Figure 25

1.0 TEST IDENTIFICATION

FTMS 791, Method 346 1-H2	Laboratory LO-030954 SwRI	Oil Code AL-15293L	
Stand No. 16	Stand Run No. 96	Engine No. 1A947	Fuel (Mfr.-Batch) Howell Hydrocarbons 86-4
Date Started 07/23/86	Date Completed 08/13/86	Test Hours 480	

2.0 REFERENCE TESTS

STAND LAST REFERENCE	Engine No. 1A947	Date Completed 09/20/85	Oil I.D. SR-0114(H) 803-2 CMIR-7052
Stand No. 16 Stand Run No. 82B	Test Rating WTD= 164.9 ,TGF= 1.0%		Industry Average WTD= 129.7 ,TGF= 17.7%
LAB LAST REFERENCE	Engine No. 1A1599	Date Completed 07/31/86	Oil I.D. SR-0141(H) 830-2 CMIR-7931
Stand No. 22 Stand Run No. 38	Test Rating WTD= 190.0 ,TGF= 38.0%		Industry Average WTD= 139.9 ,TGF= 40.2%

3.0 EVALUATION OF ENGINE PARTS

3.1 Piston Deposits (Groove Backs and Lands)

Dep.	Type	Dep. Fct.	Grooves No. 1 A,%	Grooves No. 1 Dem.	Grooves No. 2 A,%	Grooves No. 2 Dem.	Grooves No. 3 A,%	Grooves No. 3 Dem.	Grooves No. 4 A,%	Grooves No. 4 Dem.	Lands No. 2 A,%	Lands No. 2 Dem.	Lands No. 3 A,%	Lands No. 3 Dem.	Lands No. 4 A,%	Lands No. 4 Dem.
C	HC	1.000														
A	MHC	0.750														
R	MC	0.500	10	5.00												
B	LC	0.250	48	12.00	25	6.25					23	5.75	2	0.50		
O	VLC	0.150														
N	Total		58	17.00	25	6.25					23	5.75	2	0.50		
L	BL	0.100	21	2.100	5	0.500					23	2.300	5	0.500	1	0.100
A	DBRL	0.075	8	0.600	2	0.150					2	0.150	13	0.975	13	0.975
C	AL	0.050	10	0.500	3	0.150			1	0.050	5	0.250	23	1.150	12	0.600
Q	LAL	0.025	3	0.075	39	0.975	23	0.575	6	0.150	22	0.550	46	1.150	44	1.100
U	VLAL	0.010			26	0.260	51	0.510	30	0.300	25	0.250	11	0.110	28	0.280
E	RL	0.000														
R	Total		42	3.275	75	2.035	74	1.085	37	0.500	77	3.500	98	3.885	98	3.055
Clean							26		63						2	
Rating				20.275		8.285		1.085		0.500		9.250		4.385		3.055
Location Factor				1		10		35		70		3.5		20		35
Weighted Rating				20.275		82.850		37.975		35.000		32.375		87.700		106.925

Total Weighted Demerit	403.1
Top Groove Filling, %	7

New Oil Viscosity @ 40°C, cSt 98.25

RATER: AB

61 SINGLE CYLINDER ENGINE TESTS CATERPILLAR 1-H2

Figure 25 (Cont.)

TEST NO. 16-96 OIL CODE AL-15293L DATE 08/13/86

3.2 SUPPLEMENTAL PISTON DEPOSITS (GROOVE SIDES & RINGS)

DEPOSIT TYPE			CARBON			LACQUER					
			HC	MC	LC	BL	DBRL	AL	LAL	VLAL	RL
SKIRT											
UN-CROWN								15	35	50	
LINER ABOVE RING TRAVEL											
PISTON CROWN					45						
G T B	1	T							100		
R O O		B							100		
O P T	2	T				20			40		
O T		B							55		
V A O	3	T							80		
E N M		B							45		
D	4	T						5	80		
		B							40		
T	1	T						20	80		
O O		B							100		
P & F		BK			70	15	15				
	2	T							95		
B R		B							100		
O B I		BK			100						
T A N	3	T							90		
T C G		B							100		
O K S		BK							100		
M	4	T							100		
		B							100		
		BK							100		

3.3 ADDITIONAL DEPOSIT & CONDITION RATINGS

A. Piston Crown Scuffing (Nature and Quantity)

Numerous fine & coarse vertical line cuttings

B. Amount and Nature of Deposits on Oil Ring Slots

Nil

C. Piston Skirt Condition (Not Including Deposits)

Polished areas normal with few fine to coarse vertical lines

D. Liner Condition

Normal

62. SINGLE CYLINDER ENGINE TESTS CATERPILLAR 1-H2

Figure 25 (Cont.)

TEST NO. 16-96 OIL CODE AL-15293L DATE 08/13/86

4.0 OPERATIONAL AND MEASUREMENT SUMMARY

OPERATING CONDITION		MIN	MAX	AVG
Engine Speed,RPM	1800±10	1794	1805	1800
Engine Load				
BHP	Approx.33	31.9	33.3	32.[illegible]
BTU Input/Min	4950±[illegible]	49[illegible]	4958	4949
Humidity,Grains/Pound	125±5	114	135	125
Temperature,°F				
Coolant Jacket Outlet	160±5	159	161	160
Coolant Jacket Inlet	Record	150	153	152
Coolant Jacket ΔT	Record	7	9	8
Oil to Bearings	180±5	179	180	180
Inlet Air	170±5	169	170	170
Exhaust	1050±50	1050	1081	1065
Oil Cooler Inlet	Record	----	----	----
Fuel	Record	----	----	----
Pressures				
Oil to Bearings,PSI	32 Max.	28.2	30.0	28.9
Oil to Jet,PSI	24±2	23.2	24.6	23.8
Inlet Air,in.Hg.(abs)	40±0.3	39.7	40.2	40.0
Exh.Back Press.,in.H_2O	6±6	7.0	8.0	7.0
Fuel(On Test),PSI	20±2	1[illegible].0	21.0	19[illegible]
Fuel(Rate Meas),PSI	20±2	18.0	21.0	1[illegible].4
C'Case Vacuum,in.H_2O	1.0±0.5	1.0	[illegible]	1.0
Blowby,CFH	Record	9.30	13.50	11.25
Oil Consumption,#/BHP-HR	Max.			
0-120	0.004			0.00127
120-240	0.004			0.00135
240-360	0.004			0.00108
360-480	0.004			0.00105
0-480				0.00119
Coolant Flow,GPM	15.3±1	14.47	15.28	14.88
Air Fuel Ratio	23.5±1:1	23.0:1	23.2:1	23.1:1
Compression Ratio	16.4±0.5	16.3:1	16.3:1	16.3:1

MEASUREMENTS				
RING GAP INCREASE				
	NO.1	NO.2	NO.3	NO.4
	0.003	0.001	0.001	0.001
RING SIDE CLEARANCE				
	Before Test		After Test	
	MIN	MAX	MIN	MAX
1	0.0045	0.[illegible]050	0.0045	0.0050
2	0.0035	0.0040	0.0035	0.0040
3	0.0035	0.0040	[illegible]	0.0040
4	0.0015	0.0020	0.0015	0.0020
LINER WEAR STEP				
	Longitudinal		Transverse	
	0.0001		0.0003	
CONDITIONS OF RING				
FACE	Normal			
SHARPNESS	Normal			
NO. TIGHT	None			
NO. STUCK	None			

Fuel Gravity: 0 Hours 34.7, 480 Hours 34.7.
D287

REMARKS:

Figure 25 (Cont.)

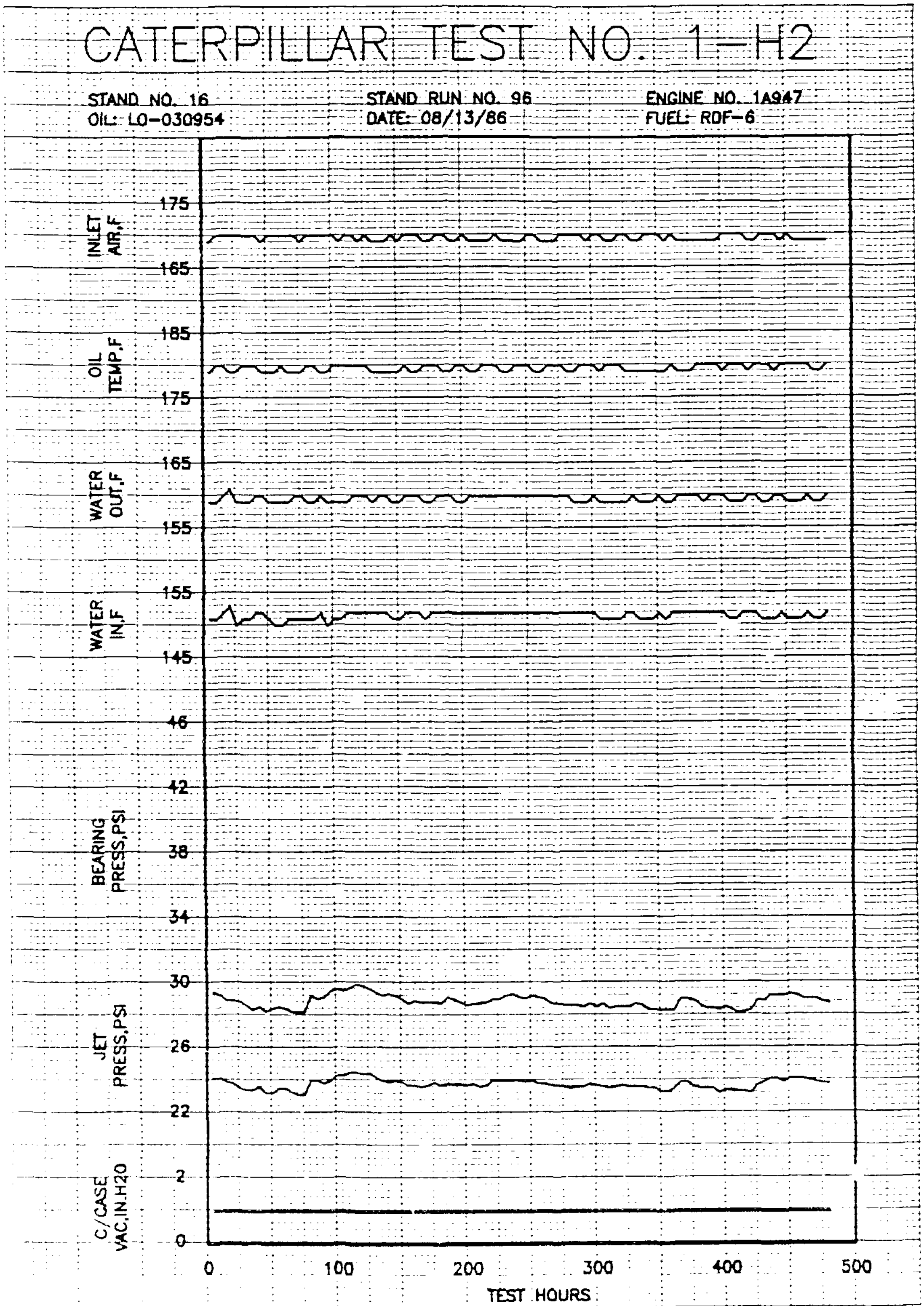
TEST No. 16-96 OIL CODE AL-15.93L DATE 08/13/86

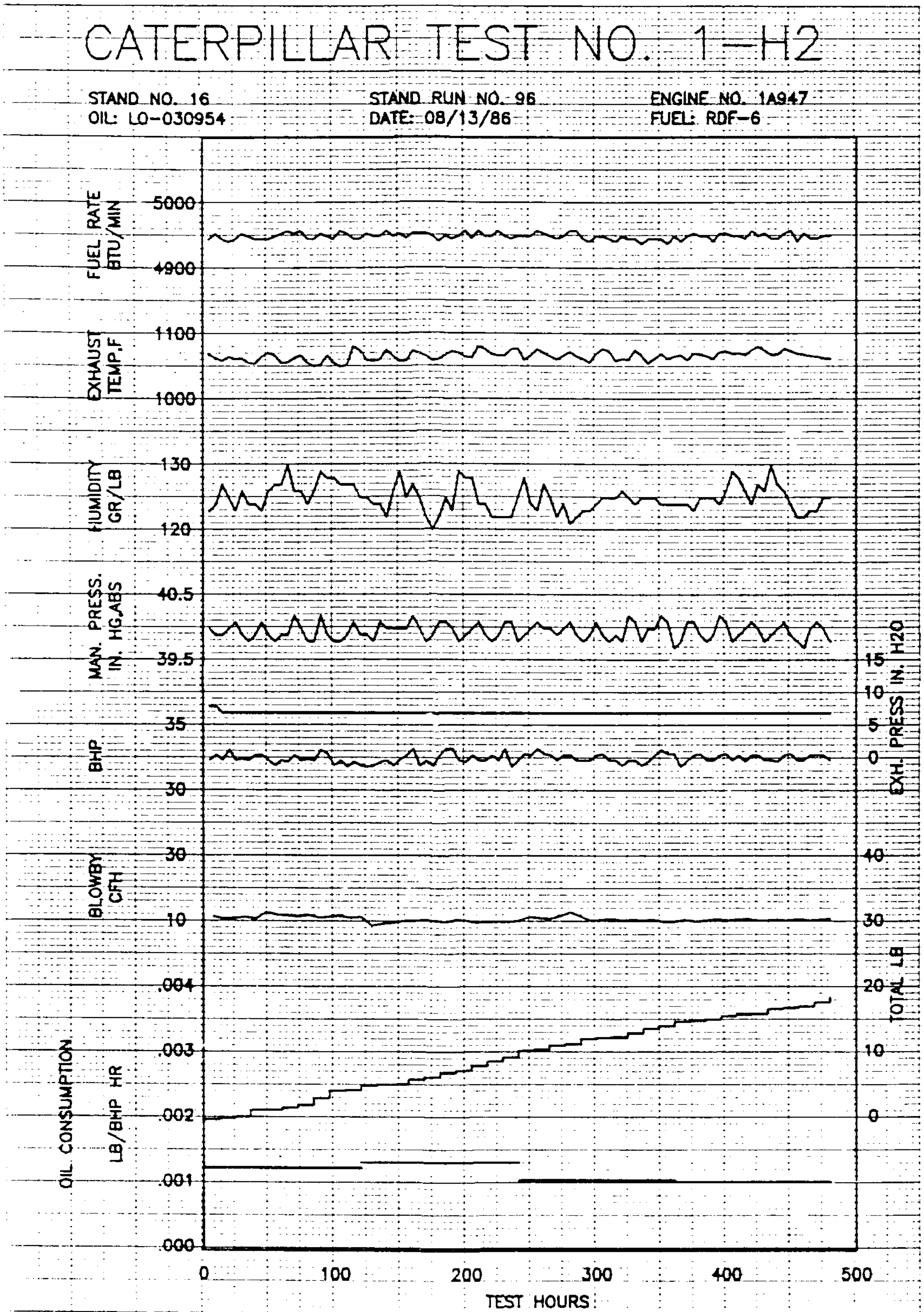
5.0 TEST LOST TIME AND INSPECTION

TEST HOURS	DATE	TIME DOWN	REMARKS
75	07/26/86	2h 30m	Replaced pump on cooling tower.
90	07/27/86	1h 24m	Boost pressure low. Tightened blower belts.
120	07/28/86	24m	Oil charge.
240	08/03/86	1h 36m	Oil change.
360	08/08/86	2h 12m	Oil change.
			Note: If no lost time state this fact.
			INSPECTION None

6.0 TEST MODIFICATIONS AND COMMENTS

Humidity - 114 grains at 7 hours.
Humidity - 135 grains at 17 hours.
Humidity - 119 grains at 45 hours.
Humidity - 118 grains at 110 hours.
Humidity - 131 grains at 400 hours.
Humidity - 119 grains at 464 hours.
Humidity - 117 grains at 467 hours.

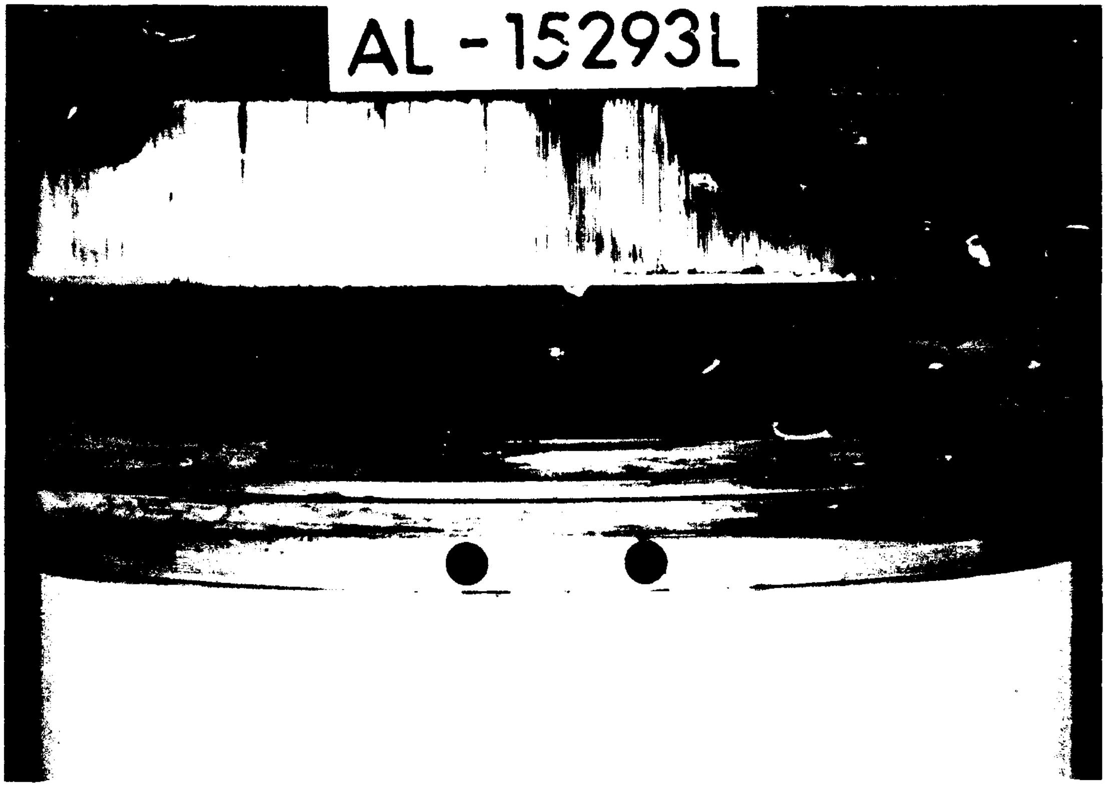

CATERPILLAR TEST NO. 1-H2
STAND NO. 16
OIL: LO-030954
STAND RUN NO. 96
DATE: 08/13/86
ENGINE NO. 1A947
FUEL: RDF-6
INLET AIR,F
175
165
OIL TEMP,F
185
175
WATER OUT,F
165
155
WATER IN,F
155
145
BEARING PRESS,PSI
46
42
38
34
JET PRESS,PSI
30
26
22
C/CASE VAC,IN.H2O
2
0
0
100
200
300
400
500
TEST HOURS

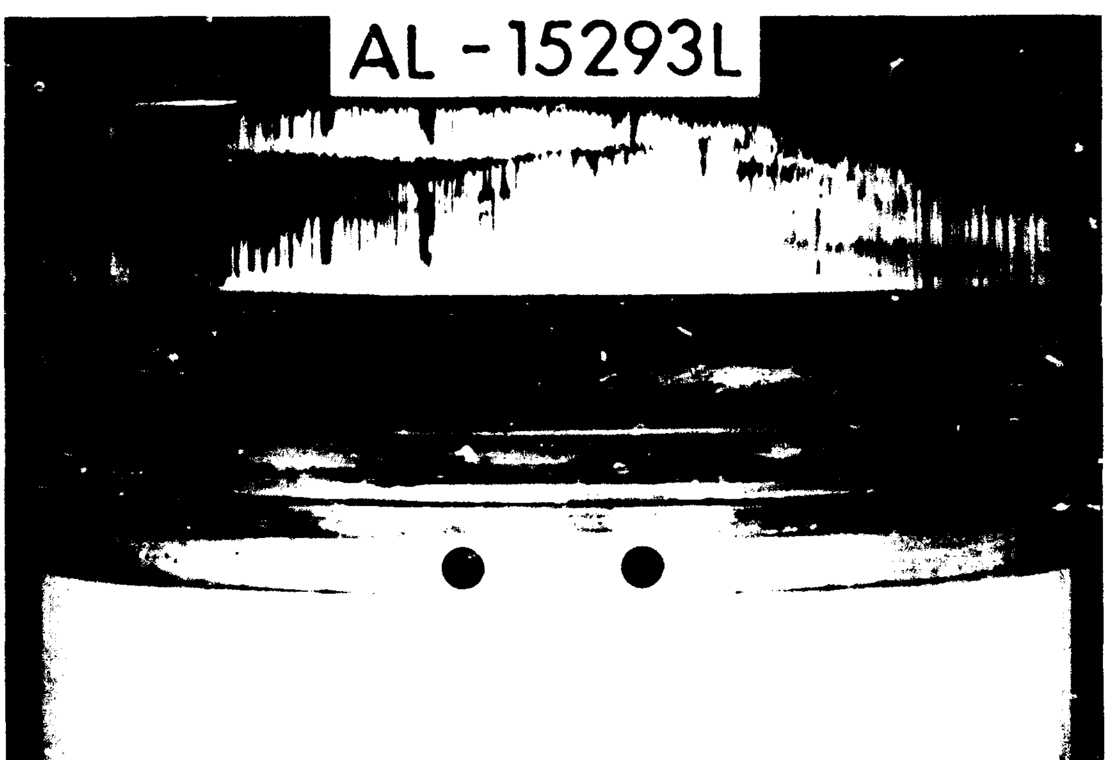

CATERPILLAR TEST NO. 1—H2
STAND NO. 16
OIL: LO-030954
STAND RUN NO. 96
DATE: 08/13/86
ENGINE NO. 1A947
FUEL: RDF-6
FUEL RATE BTU/MIN
5000
4900
EXHAUST TEMP,F
1100
1000
HUMIDITY GR/LB
130
120
MAN. PRESS. IN. HG,ABS
40.5
39.5
BHP
35
30
EXH. PRESS IN. H2O
15
10
5
0
BLOWBY CFH
30
10
40
30
OIL CONSUMPTION LB/BHP HR
.004
.003
.002
.001
.000
TOTAL LB
20
10
0
0
100
200
300
400
500
TEST HOURS

FUEL INSPECTION

HOWELL HYDROCARBONS LOW SULFUR DIESEL FUEL - BATCH 86-4

Gravity, °API	34.7
Flash Point, °F	195
Water and Sediment, % v	<0.05
Pour Point, °F	+ 12
Carbon Residue, % wt.	0.10
Ash, % wt.	<.001
Distillation	
IBP	410
10%	466
50%	528
90%	614
End Point	650
Recovery, %	---
Kinematic Viscosity, Centistokes @ 100°F	3.36
Sulfur, % wt.	0.43
Corrosion	1A
Neutralization No. TAN	0.04
Centane Number Cal.	49.4


AL-15293L


AL-15293L

SOUTHWEST RESEARCH INSTITUTE
San Antonio, Texas

DIVISION OF
ENGINES, FUELS AND LUBRICANTS

CATERPILLAR 1-H2 LUBRICANT EVALUATION

Conducted for

FORT BELVOIR FUEL & LUBRICANTS

on Test Oil

AL-14777

63A Single Cylinder Engine Tests
7.0 Test Certification
1H2 TEST STAND CALIBRATION STATEMENT

Test No. 21-77 for evaluation of oil AL-14777 has, in my opinion been conducted in a valid manner in accordance to STP 509A Part II and appropriate amendments by the information letter system. The detailed remarks provided in this report describe the deviations and any unusual features associated with this test.

The test stand has been calibrated in accordance to the requirements specified in ASTM STP 509A Part II and the appropriate amendments through the information letter system.

SwRI

Mark R. Sutherland
Research Engineer

September 12, 1986

This Caterpillar 1-H2 evaluation was conducted to determine the effect of the lubricant on ring sticking, wear, and accumulation of deposits.

The evaluation was run in accordance with the Federal Test Method 346 (1-H2) dated February 15, 1977, with the indicated modifications, if any. The operating conditions were those specified for this supercharged diesel test, and a fuel of 0.35% minimum sulfur content was used.

Tabulated on the following pages is a summary of the results at the conclusion of the 480 hour procedure. Piston deposit ratings and tabulations and a graph of the test operating conditions are included.

Figure 25

1.0 TEST IDENTIFICATION

FTMS 791, Method		Laboratory		Oil Code AL-14777
346	1-H2	LO-031342	SwRI	

Stand No.	Stand Run No.	Engine No.	Fuel (Mfr.-Batch)
21	77	1A2010	Howell Hydrocarbons 86-5

Date Started	Date Completed	Test Hours
08/22/86	09/12/86	480

2.0 REFERENCE TESTS

STAND LAST REFERENCE		Engine No.	Date Completed	Oil I.D.	800
Stand No.	Stand Run No.	1A2010	02/18/86	SR-0191(G)	CMIR-7130
21	68	Test Rating WTD= 108.5 ,TGF= 42.0%		Industry Average WTD= 136.7 ,TGF= 24.4%	

LAB LAST REFERENCE		Engine No.	Date Completed	Oil I.D.	803-2
Stand No.	Stand Run No.	1A122	08/23/86	SR-0144(H)	CMIR-7934
47	39	Test Rating WTD= 156.7 ,TGF= 32.0%		Industry Average WTD= 129.2 ,TGF= 14.4%	

3.0 EVALUATION OF ENGINE PARTS

3.1 Piston Deposits (Groove Backs and Lands)

			Grooves								Lands					
Dep.		Dep.	No. 1		No. 2		No. 3		No. 4		No. 2		No. 3		No. 4	
Type		Fct.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
C	HC	1.000	4	4.00												
A	MHC	0.750														
R	MC	0.500	8	4.00												
B	LC	0.250	30	7.50	8	2.00					1	0.25				
O	VLC	0.150														
N	Total		42	15.50	8	2.00					1	0.25				
L	BL	0.100	21	2.100	20	2.000					12	1.200				
A	DBRL	0.075														
C	AL	0.050									2	0.100				
Q	LAL	0.025	37	0.925	13	0.325					14	0.350				
U	VLAL	0.010			24	0.240					42	0.420	4	0.040	2	0.020
E	RL	0.000														
R	Total		58	3.025	57	2.565					70	2.070	4	0.040	2	0.020
Clean					35		100		100		29		96		98	
Rating				18.525		4.565		0.000		0.000		2.320		0.040		0.020
Location Factor				1		10		35		70		3.5		20		35
Weighted Rating				18.525		45.650		0.000		0.000		8.120		0.800		0.700

Total Weighted Demerit	73.8
Top Groove Filling, %	10

New Oil Viscosity @ 40°C, cSt 93.08

RATER: RV

Figure 25 (Cont.)

TEST NO. 21-77 OIL CODE AL-14777 DATE 09/12/86

3.2 SUPPLEMENTAL PISTON DEPOSITS (GROOVE SIDES & RINGS)

DEPOSIT TYPE			CARBON			LACQUER					
			HC	MC	LC	BL	DBRL	AL	LAL	VLAL	RL
SKIRT											
UN-CROWN									30	30	
LINER ABOVE RING TRAVEL											
PISTON CROWN			2		52						
GROOVE TOP AND BOTTOM	1	T							100		
		B							100		
	2	T							15		
		B							20		
	3	T							45		
		B							30		
	4	T							60		
		B							40		
TOP BOTTOM & BACK OF RINGS	1	T							100		
		B							100		
		BK			70	30					
	2	T							40		
		B							85		
		BK			10	90					
	3	T							100		
		B							100		
		BK							100		
	4	T							60		
		B							25		
		BK							80		

3.3 ADDITIONAL DEPOSIT & CONDITION RATINGS

A. Piston Crown Scuffing (Nature and Quantity)

Numerous coarse & few fine vertical line cuttings

B. Amount and Nature of Deposits on Oil Ring Slots

Nil

C. Piston Skirt Condition (Not Including Deposits)

Polished areas normal with few fine to coarse vertical lines

D. Liner Condition

Normal

62a SINGLE CYLINDER ENGINE TESTS CATERPILLAR 1-H2

Figure 25 (Cont.)

TEST NO. 21-77 OIL CODE AL-14777 DATE 09/12/86

4.0 OPERATIONAL AND MEASUREMENT SUMMARY

OPERATING CONDITION		MIN	MAX	AVG
Engine Speed,RPM	1800±10	1795	1804	1800
Engine Load				
BHP	Approx.33	31.9	33.8	32.6
BTU Input/Min	4950±50	4937	4962	4949
Humidity,Grains/Pound	125±5	116	133	124
Temperature,°F				
Coolant Jacket Outlet	160±5	158	162	160
Coolant Jacket Inlet	Record	149	153	151
Coolant Jacket ΔT	Record	8	9	9
Oil to Bearings	180±5	178	181	180
Inlet Air	170±5	168	171	170
Exhaust	1050±50	1060	1099	1081
Oil Cooler Inlet	Record	----	----	----
Fuel	Record	----	----	----
Pressures				
Oil to Bearings,PSI	32 Max.	29.2	31.5	30.2
Oil to Jet,PSI	24±2	23.0	24.4	23.6
Inlet Air,in.Hg.(abs)	40±0.3	39.8	40.2	39.9
Exh.Back Press.,in.H_2O	6±6	7.0	11.0	8.9
Fuel(On Test),PSI	20±2	19.0	22.0	20.5
Fuel(Rate Meas),PSI	20±2	19.0	22.0	20.5
C'Case Vacuum,in.H_2O	1.0±0.5	1.0	1.0	1.0
Blowby,CFH	Record	8.40	10.20	9.31
Oil Consumption,#/BHP-HR	Max.			
0-120	0.004			0.00100
120-240	0.004			0.00121
240-360	0.004			0.00193
360-480	0.004			0.00222
0-480				0.00159
Coolant Flow,GPM	15.3±1	15.08	16.04	15.56
Air Fuel Ratio	23.5±1:1	22.7:1	22.9:1	22.8:1
Compression Ratio	16.4±0.5	16.3:1	16.3:1	16.3:1

MEASUREMENTS			
RING GAP INCREASE			
NO.1	NO.2	NO.3	NO.4
0.003	0.002	0.001	0.001
RING SIDE CLEARANCE			
Before Test		After Test	
MIN	MAX	MIN	MAX
1 0.0045	0.0050	0.0050	0.0055
2 0.0035	0.0040	0.0035	0.0040
3 0.0035	0.0040	0.0035	0.0040
4 0.0015	0.0020	0.0015	0.0020
LINER WEAR STEP			
Longitudinal		Transverse	
0.0002		0.0003	
CONDITIONS OF RING			
FACE	Normal		
SHARPNESS	Normal		
NO. TIGHT	None		
NO. STUCK	None		

Fuel Gravity: 0 Hours 34.9, 480 Hours 34.9.
D287

REMARKS:

63 SINGLE CYLINDER ENGINE TESTS CATERPILLAR 1-H2

Figure 25 (Cont.)

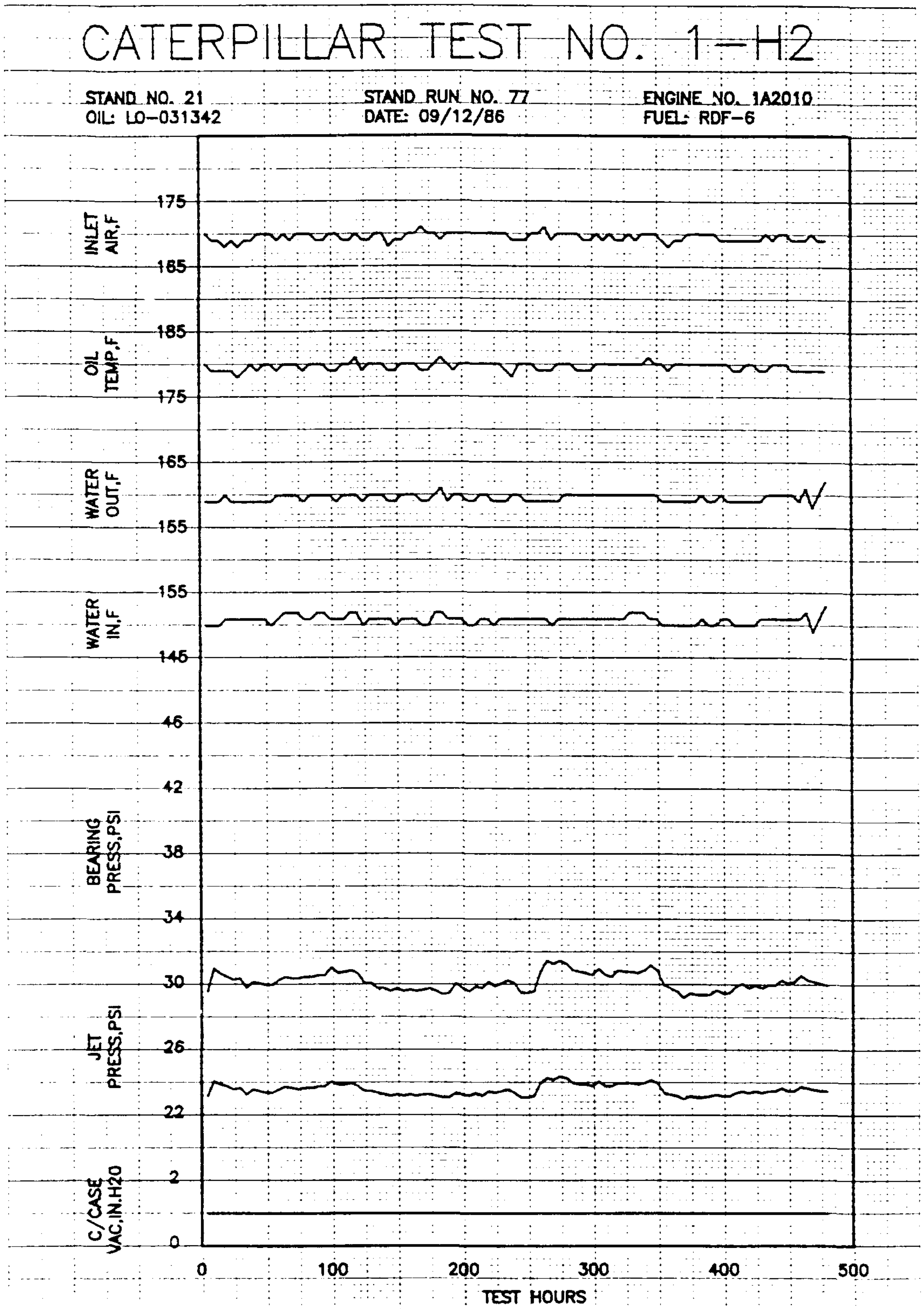
TEST NO. 21-77 OIL CODE AL-14777 DATE 09/12/86

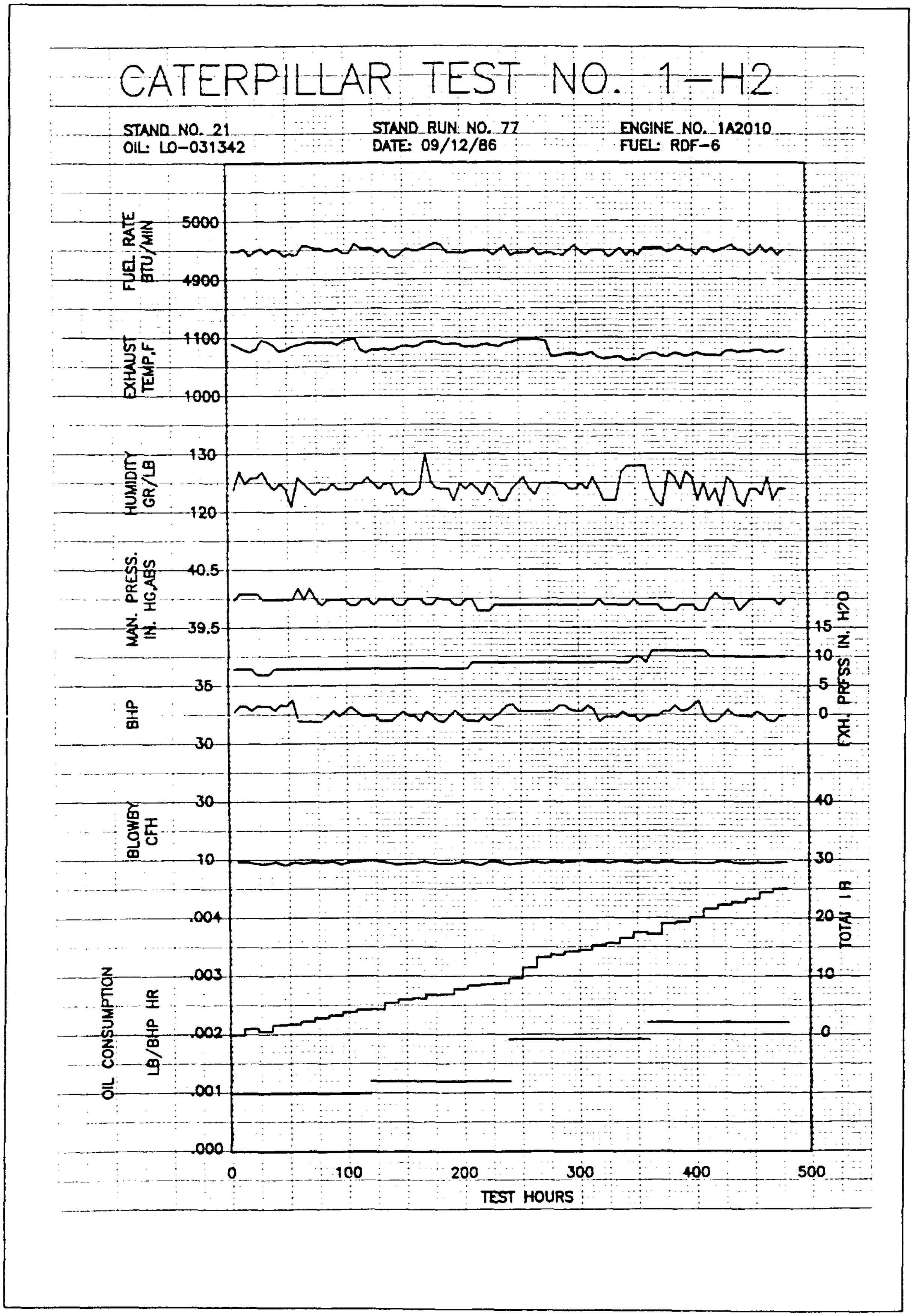
5.0 TEST LOST TIME AND INSPECTION

TEST HOURS	DATE	TIME DOWN	REMARKS
120	08/28/86	4h 54m	Oil change.
240	09/02/86	1h 30m	Oil change.
348	09/07/86	1h 18m	Replaced fuel filters.
360	09/07/86	1h 54m	Oil change.
			Note: If no lost time state this fact.
			INSPECTION None

6.0 TEST MODIFICATIONS AND COMMENTS

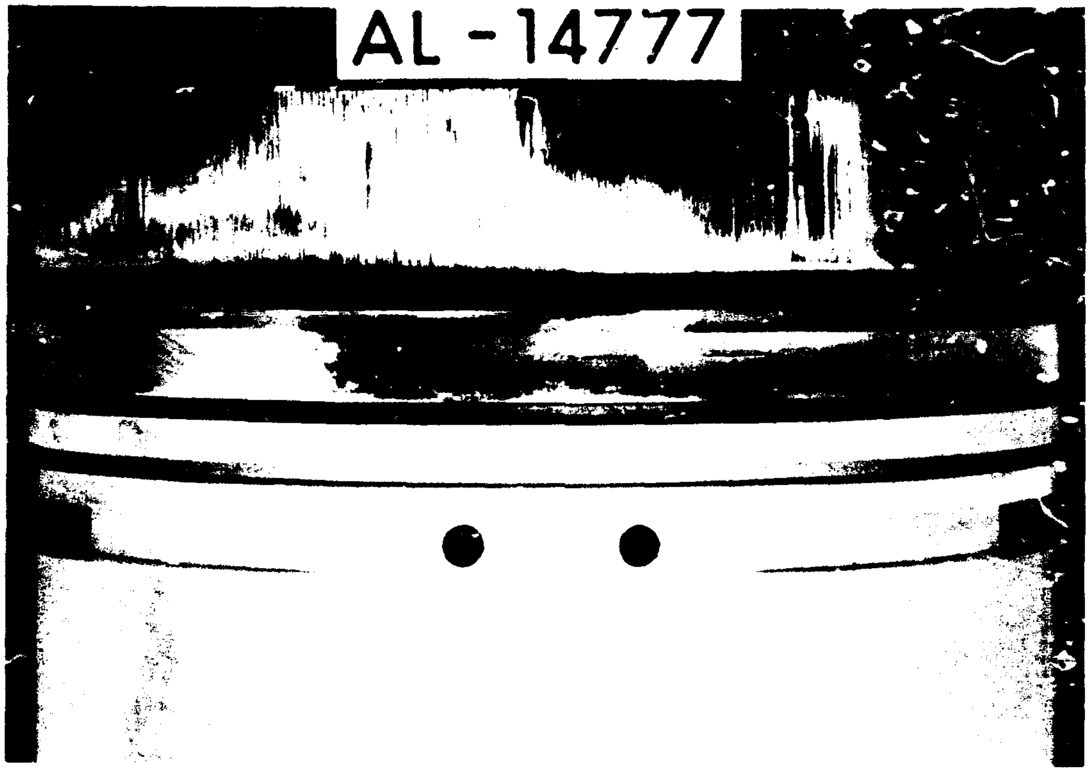
Humidity - 133 grains at 26 hours.
Humidity - 116 grains at 54 hours.
Humidity - 119 grains at 73 hours.
Humidity - 117 grains at 194 hours.
Humidity - 117 grains at 373 hours.
Humidity - 119 grains at 421 hours.
Humidity - 119 grains at 439 hours.
Humidity - 119 grains at 456 hours.


CATERPILLAR TEST NO. 1-H2
STAND NO. 21
OIL: LO-031342
STAND RUN NO. 77
DATE: 09/12/86
ENGINE NO. 1A2010
FUEL: RDF-6
INLET AIR,F
175
165
OIL TEMP,F
185
175
WATER OUT,F
165
155
WATER IN,F
155
145
BEARING PRESS,PSI
46
42
38
34
30
JET PRESS,PSI
26
22
C/CASE VAC,IN.H20
2
0
0
100
200
300
400
500
TEST HOURS


CATERPILLAR TEST NO. 1-H2
STAND NO. 21
OIL: LO-031342
STAND RUN NO. 77
DATE: 09/12/86
ENGINE NO. 1A2010
FUEL: RDF-6
FUEL RATE BTU/MIN
EXHAUST TEMP,F
HUMIDITY GR/LB
MAN. PRESS. IN. HG,ABS
BHP
BLOWBY CFH
OIL CONSUMPTION LB/BHP HR
EXH. PRESS IN. H2O
TOTAL LB
TEST HOURS

FUEL INSPECTION
HOWELL HYDROCARBONS LOW SULFUR DIESEL FUEL - BATCH 86-5

Gravity, °API	34.9
Flash Point, °F	191
Water and Sediment, % v	<0.05
Pour Point, °F	+ 15
Carbon Residue, % wt.	0.18
Ash, % wt.	<.001
Distillation	
IBP	396
10%	467
50%	525
90%	610
End Point	654
Recovery, %	---
Kinematic Viscosity, Centistokes @ 100°F	3.28
Sulfur, % wt.	0.41
Corrosion	1A
Neutralization No. TAN	0.09
Centane Number Cal.	47.8

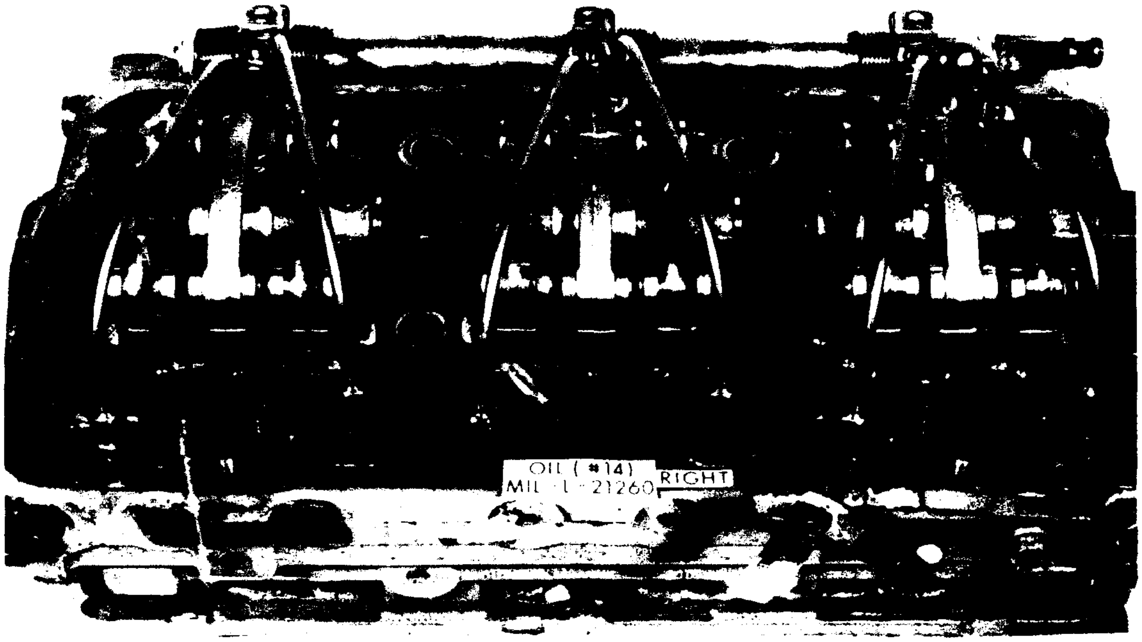

AL - 14777

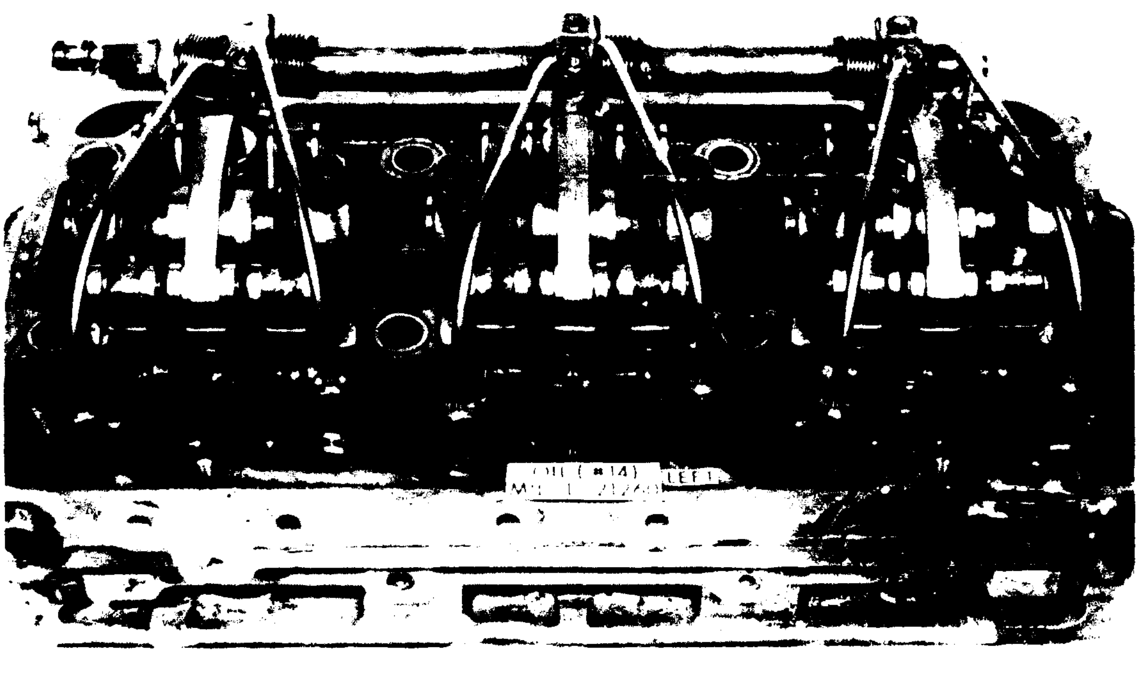

AL - 14777

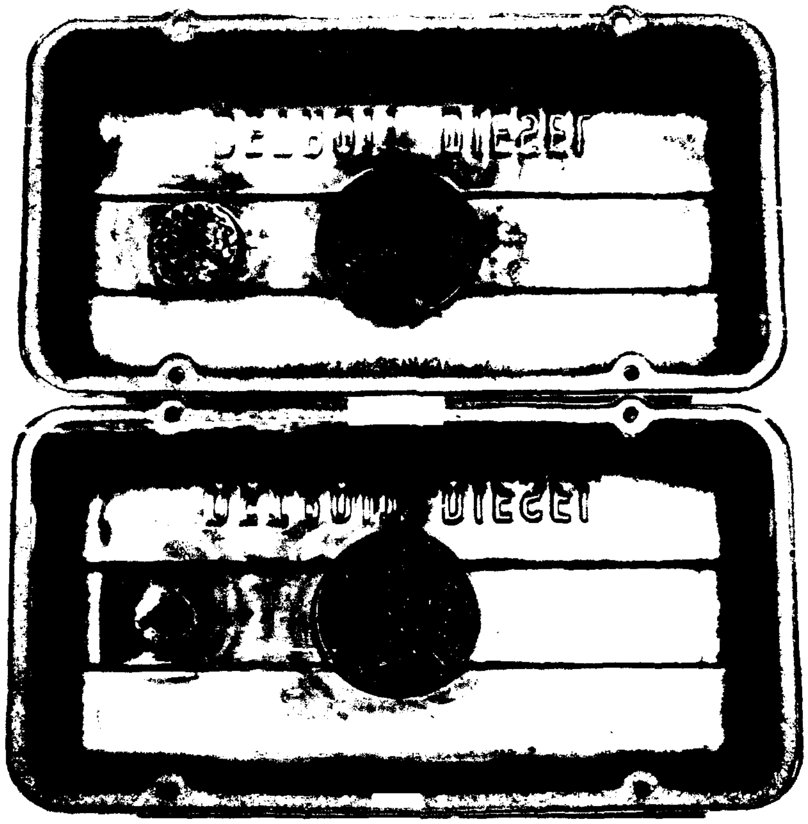
APPENDIX C

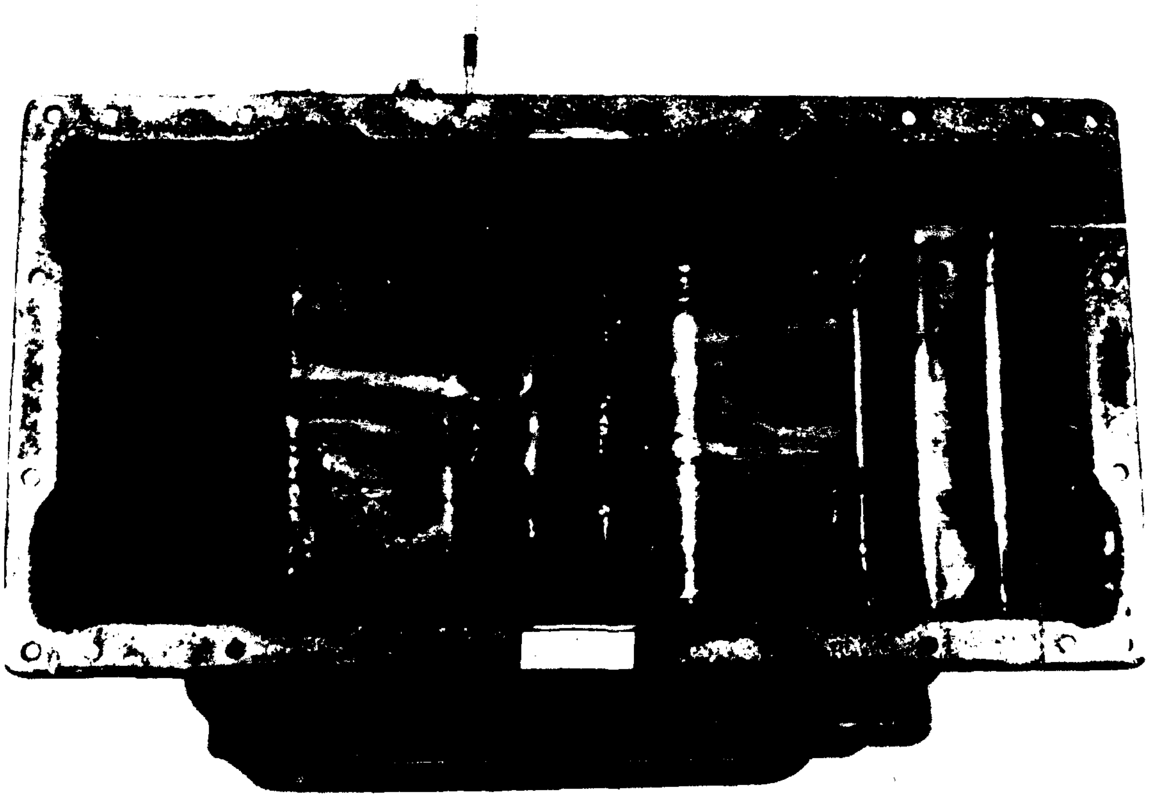
Photographs of 6V-53T Engine Parts After 1-, 2-, and 3-Year Storage

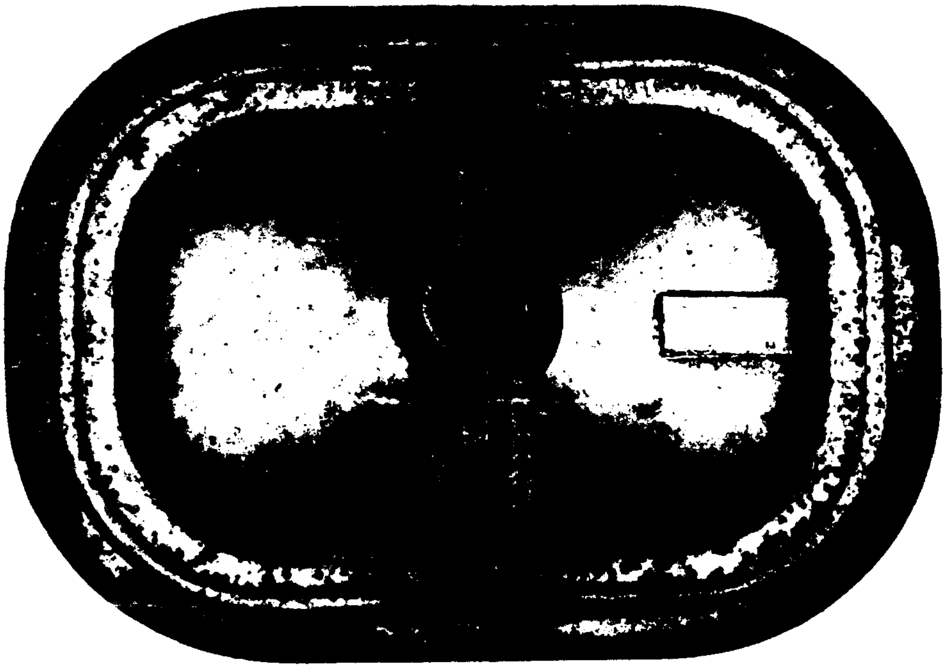
1-Year Storage


OIL (#14)
MIL-L-21260
RIGHT

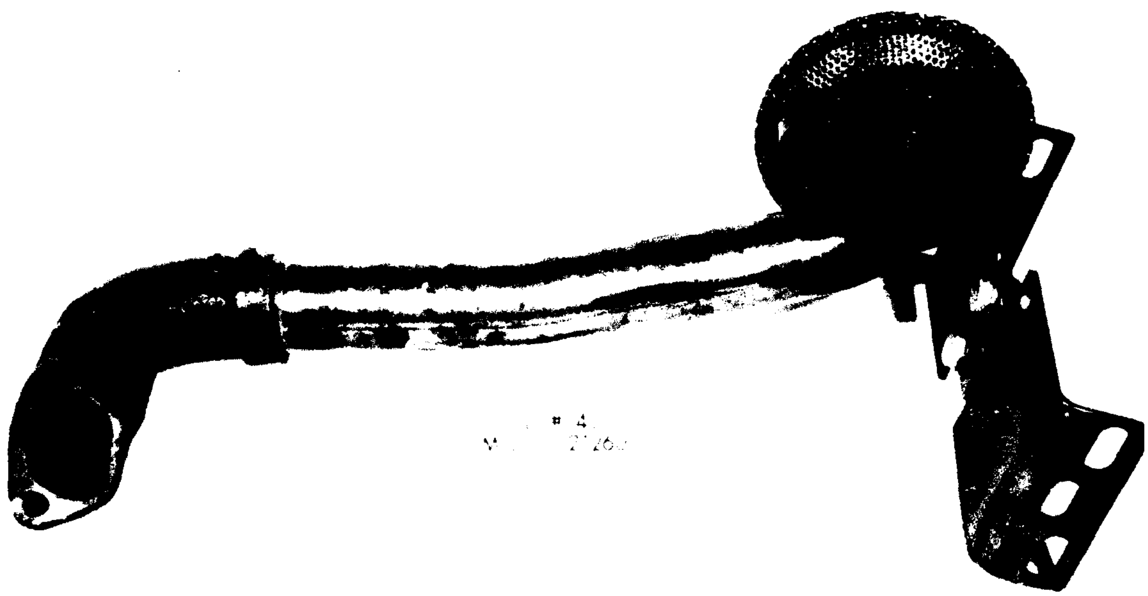

OIL (#14)
LEFT

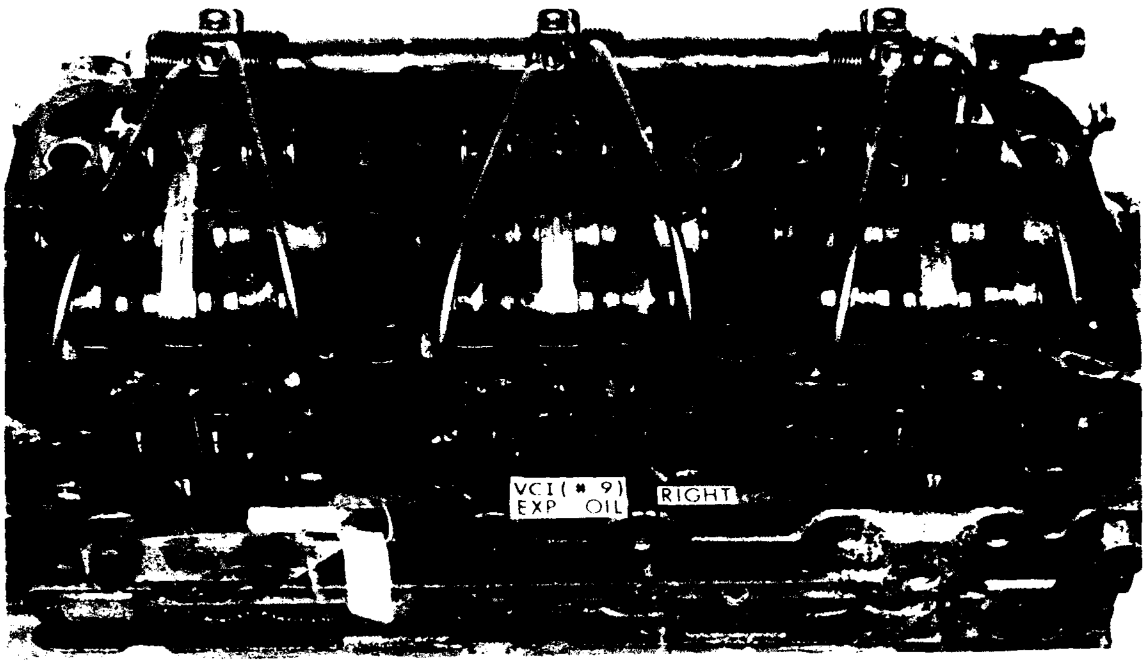


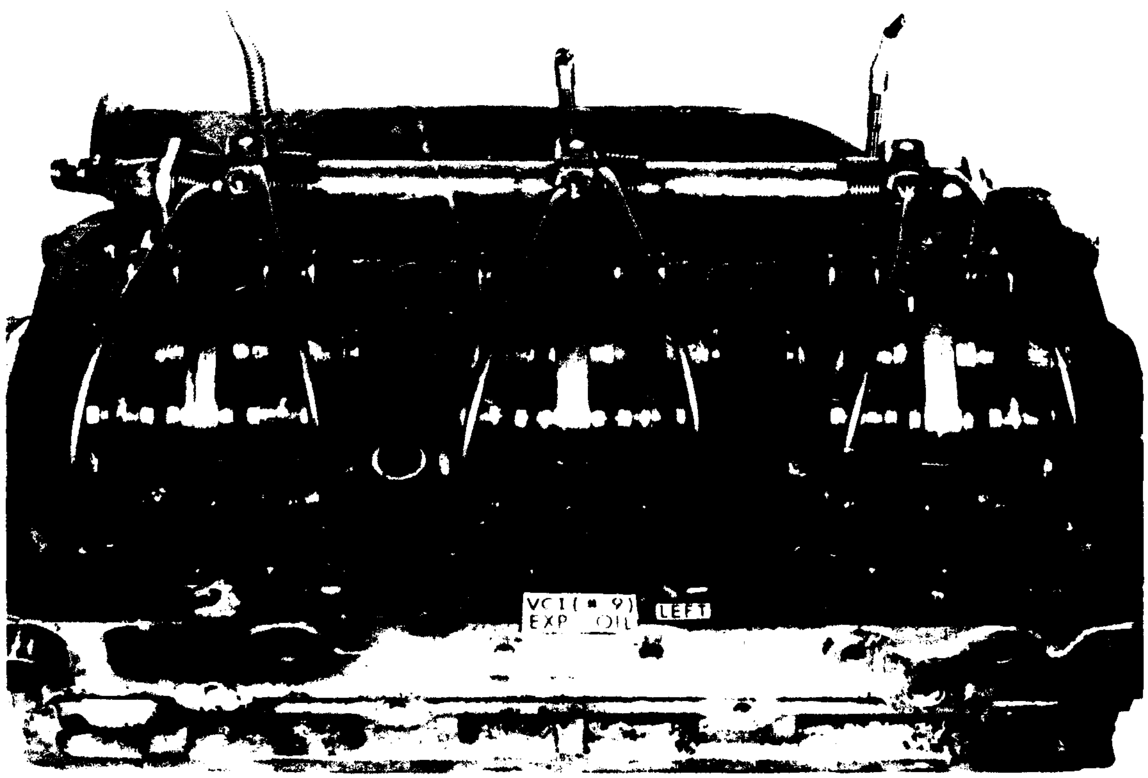


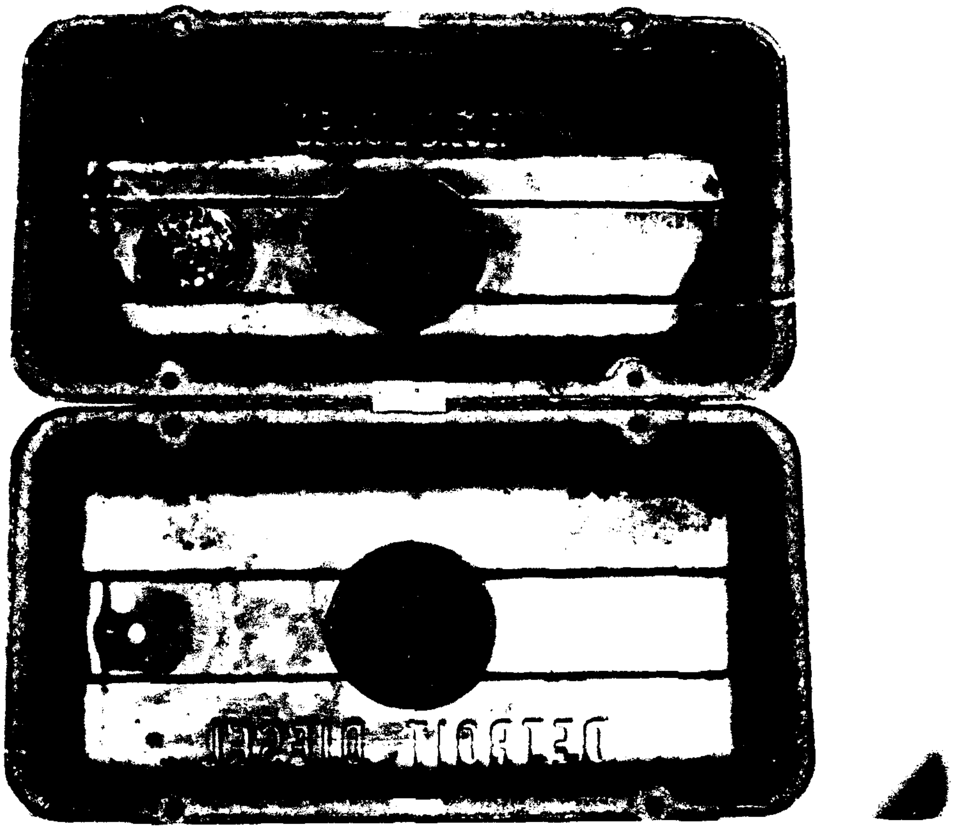


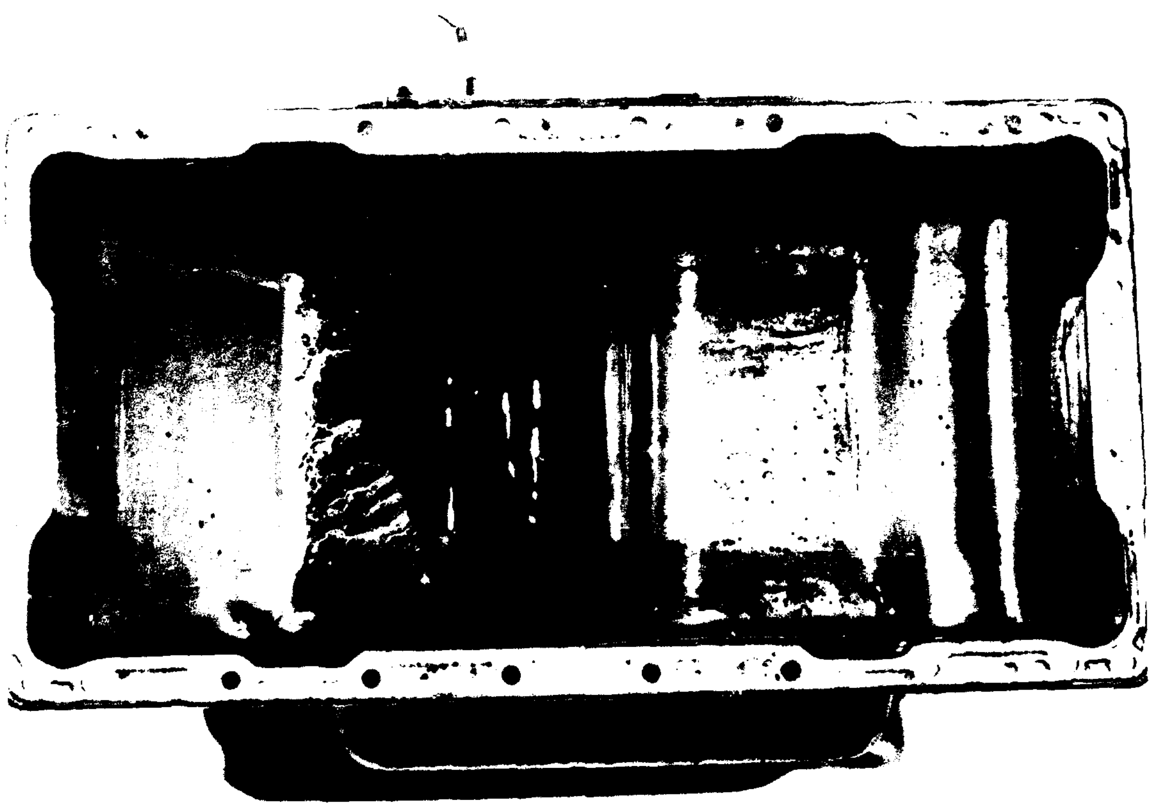
OIL (#14)
MIL-L-21260
RIGHT

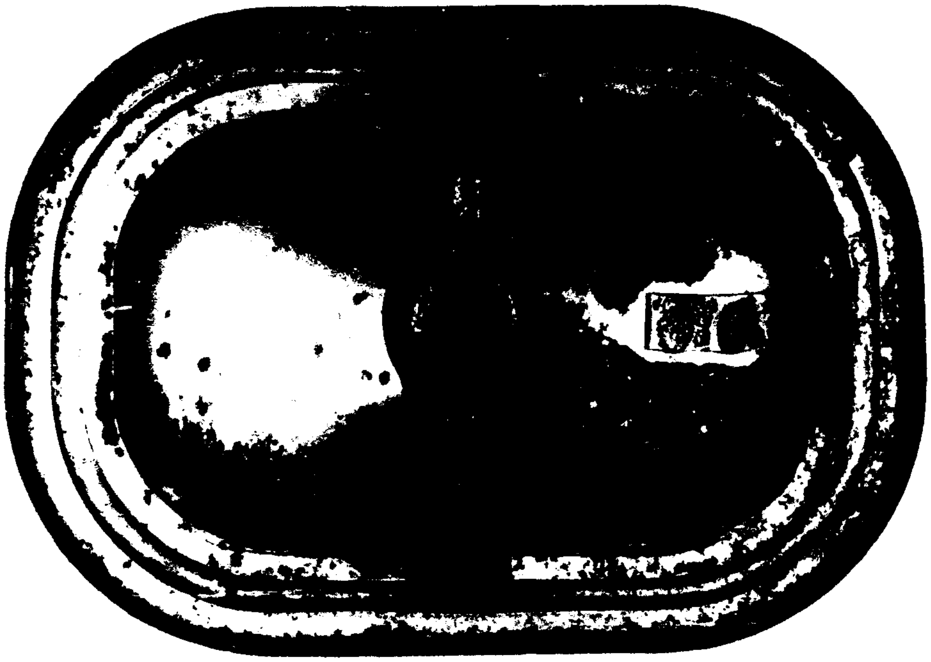



VCI (# 9)
EXP OIL
RIGHT

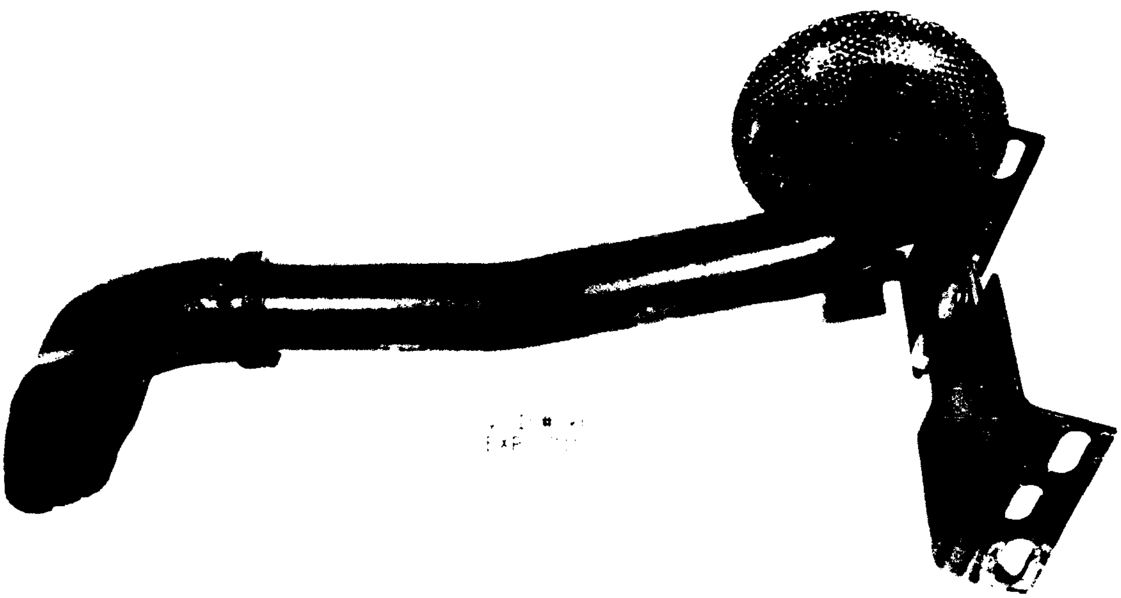

VCI (# 9)
EXP OIL
LEFT



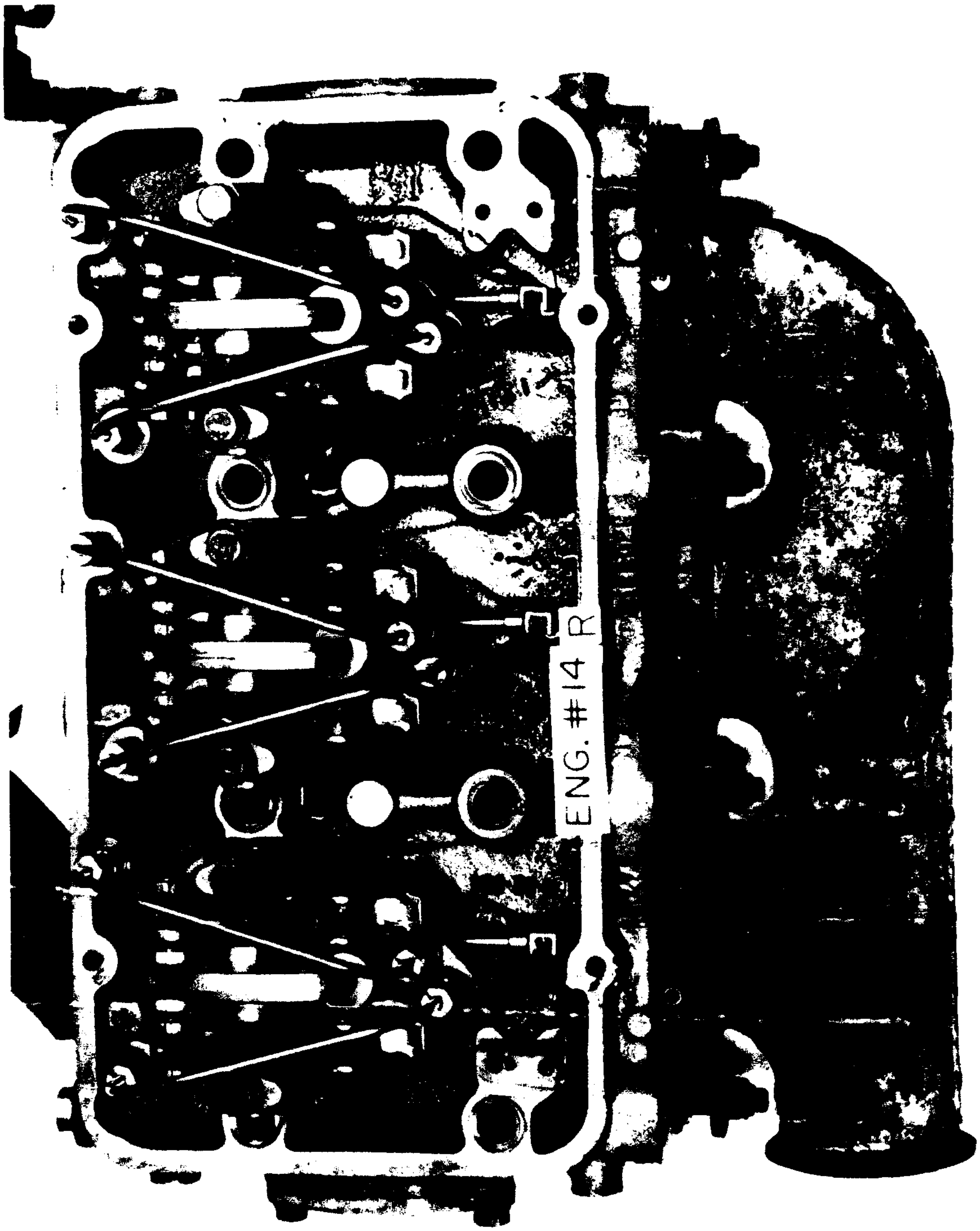




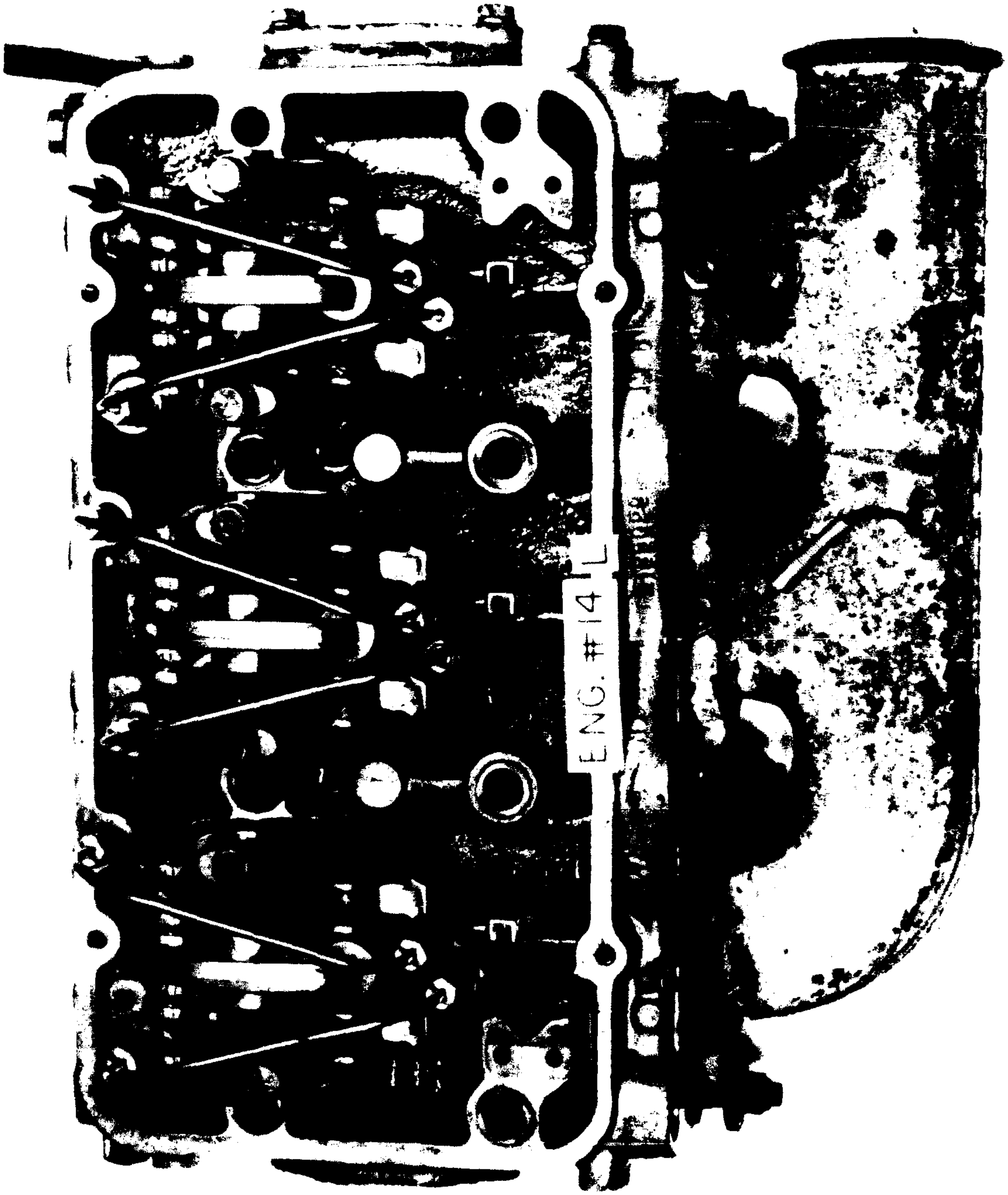
VCI(# 9)
EXP. OIL
LEFT



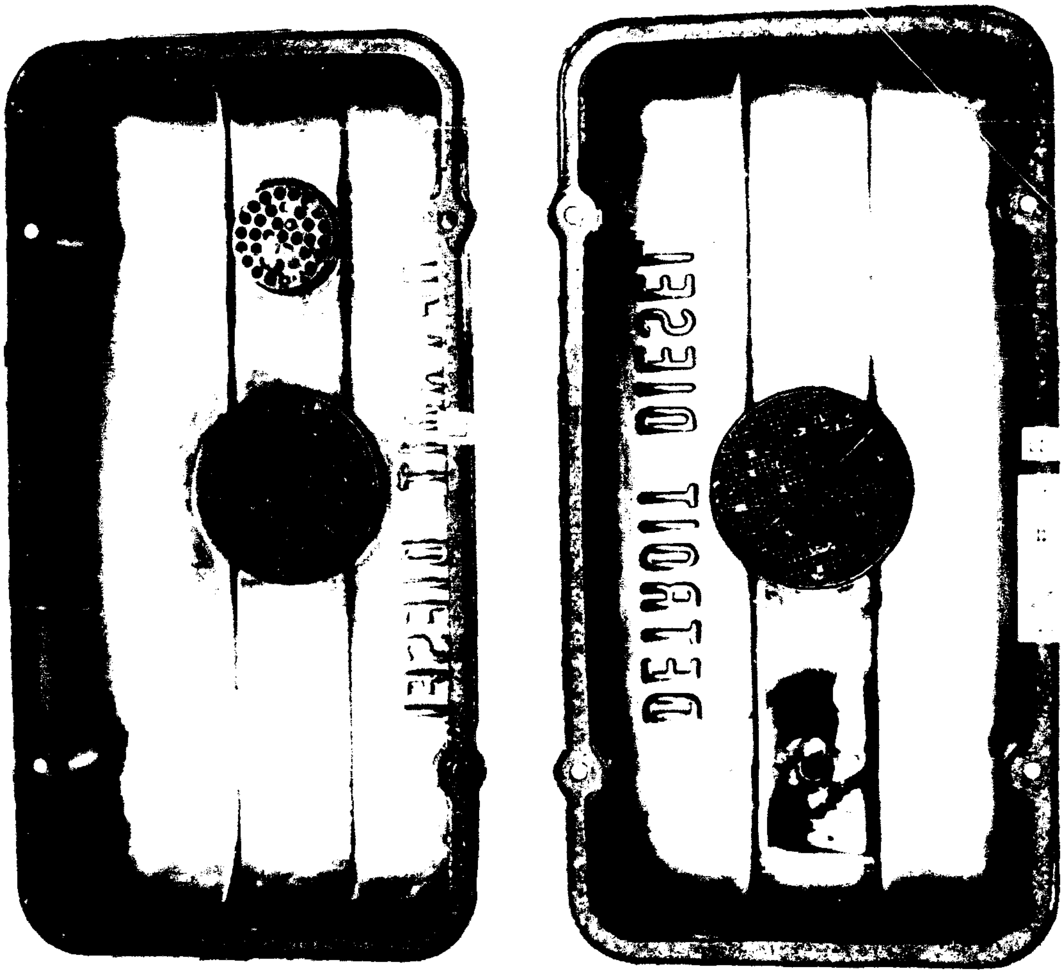
2-Year Storage



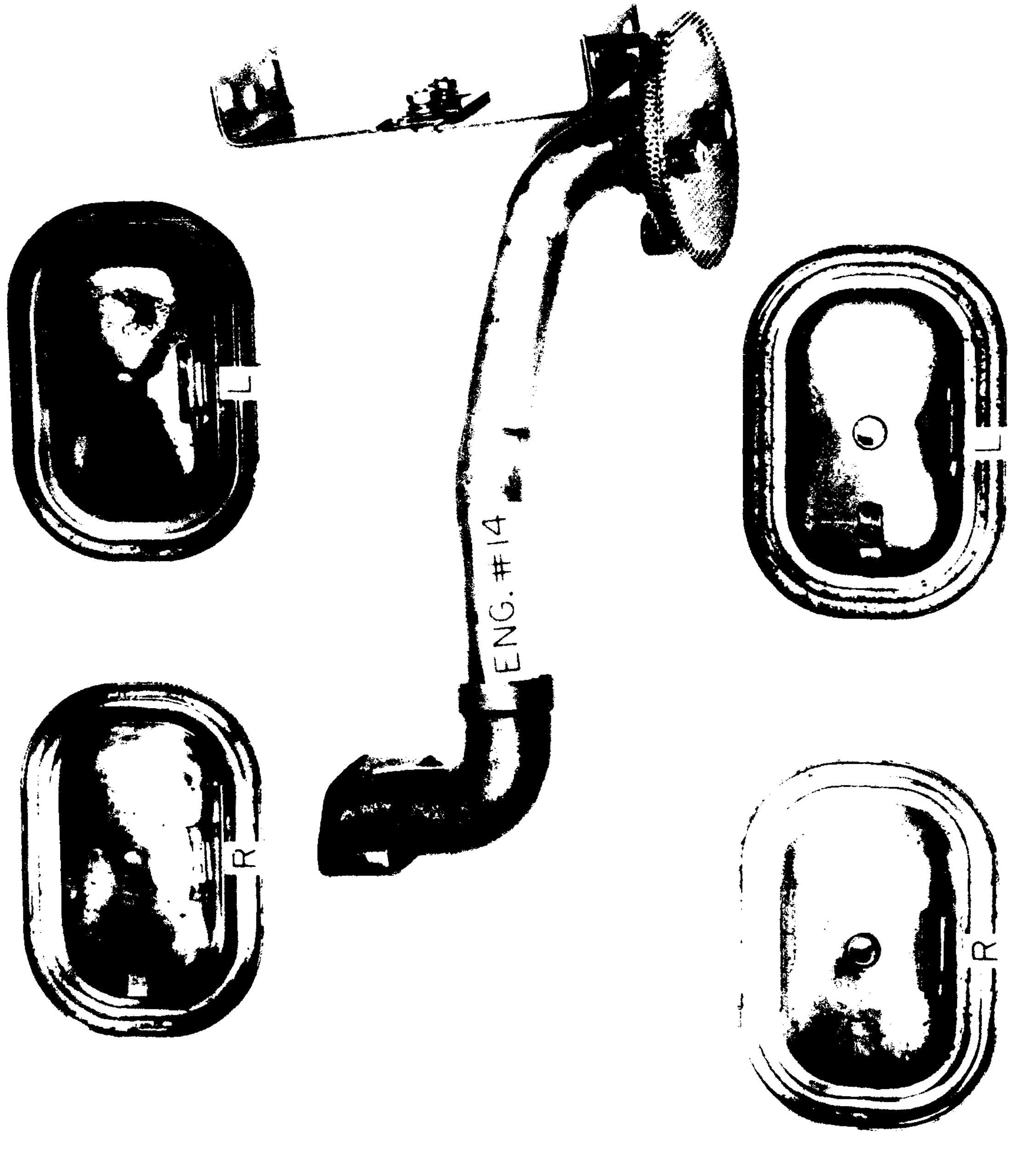
PEO



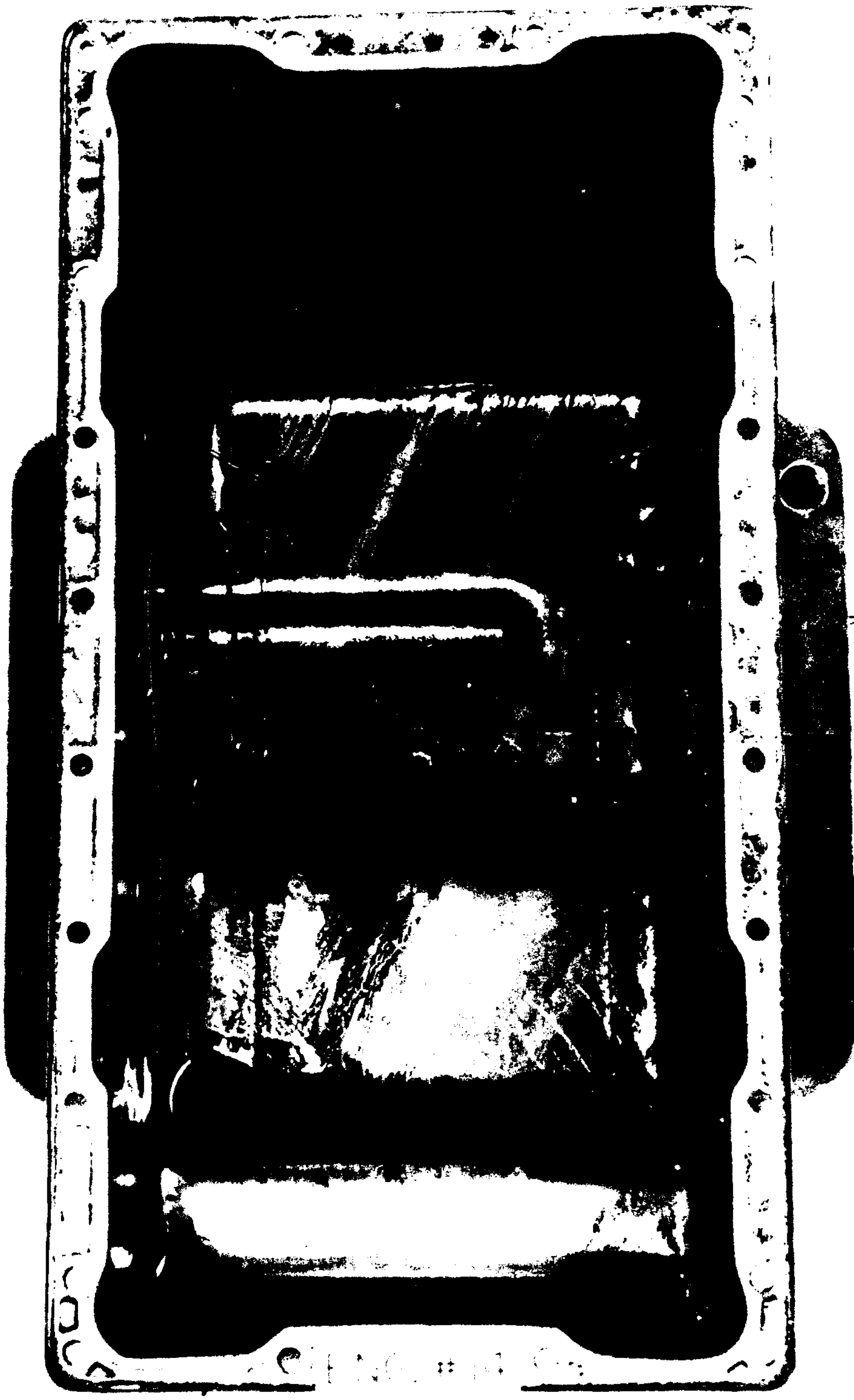
PEO



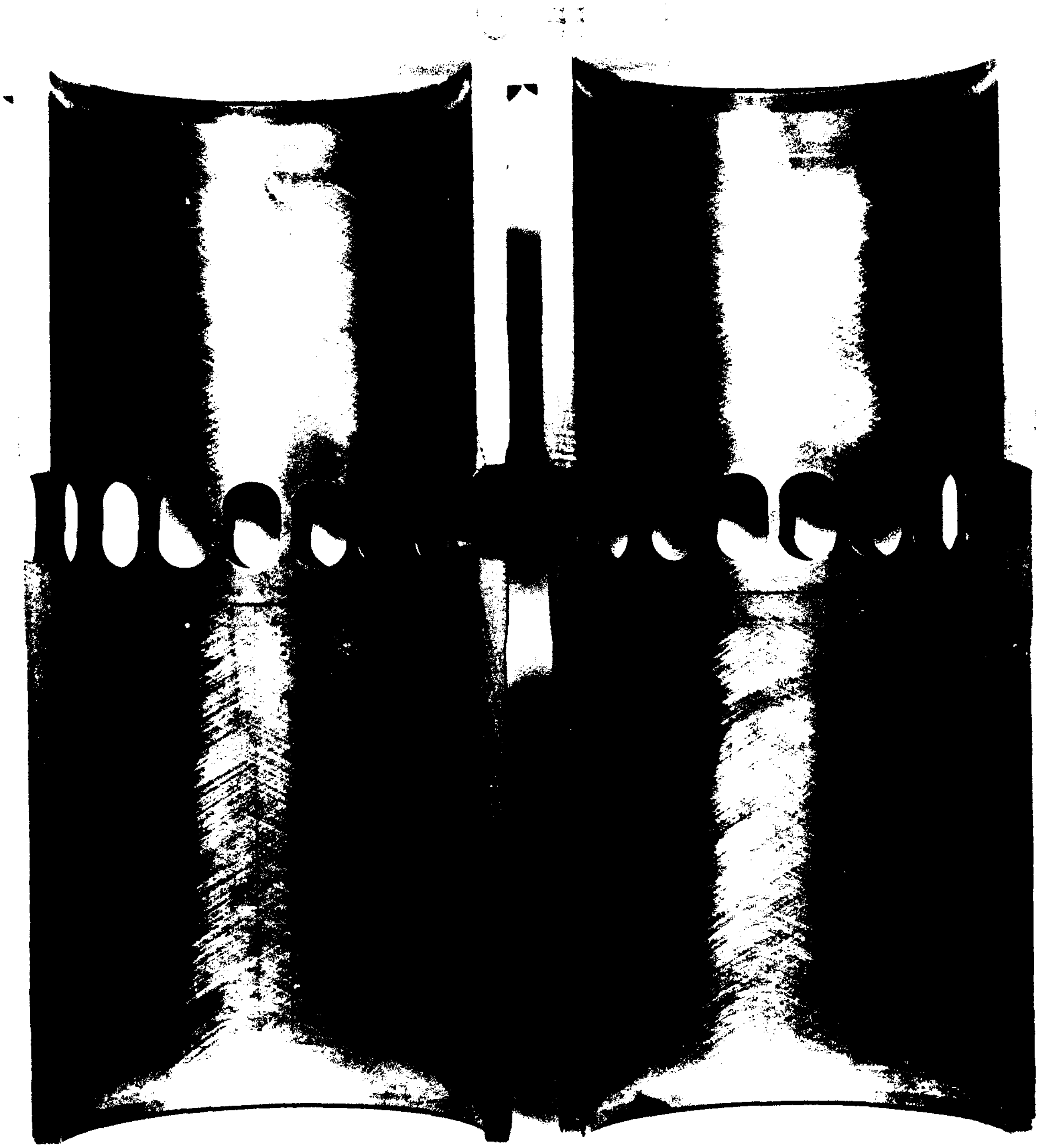
PEO



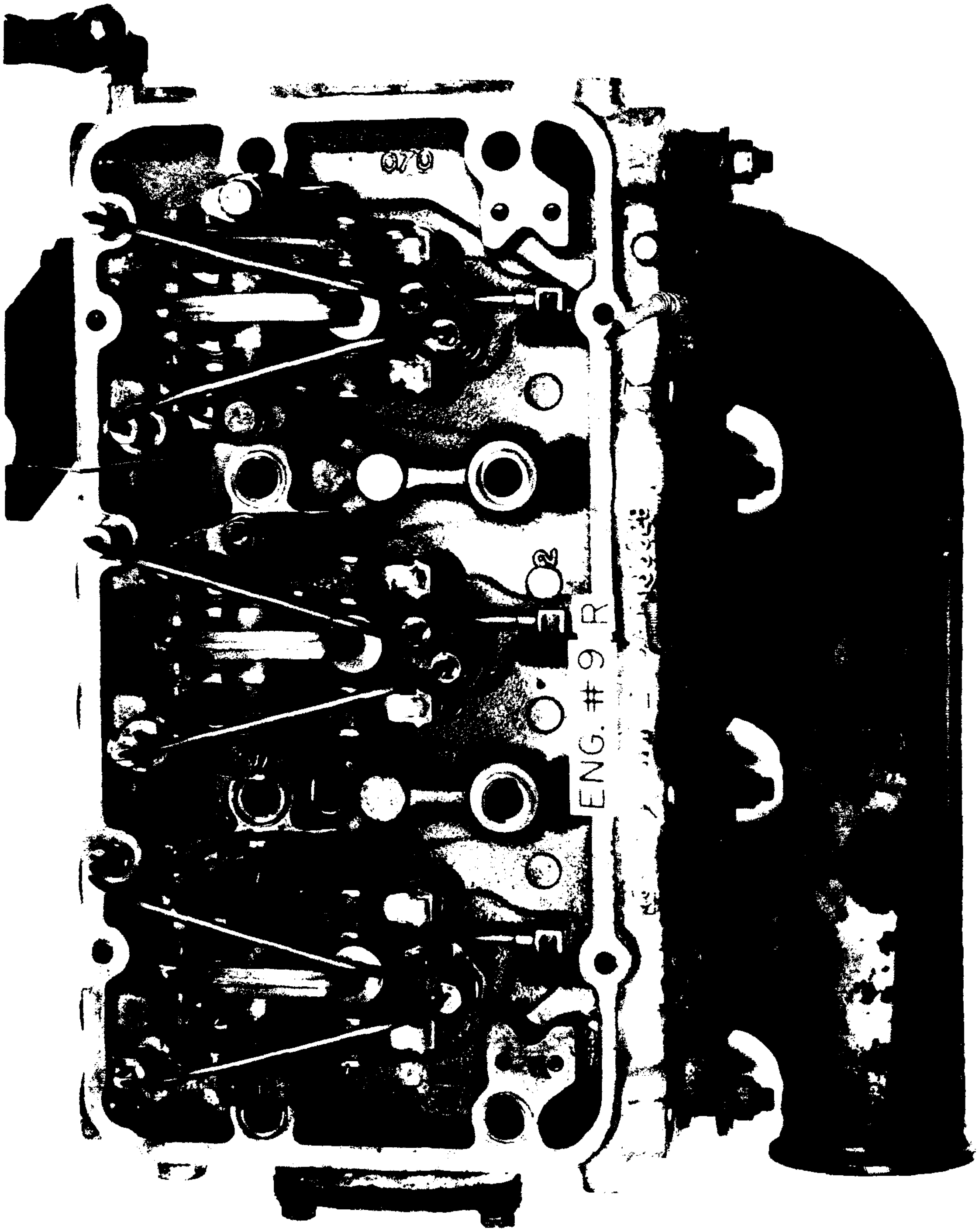
PEO



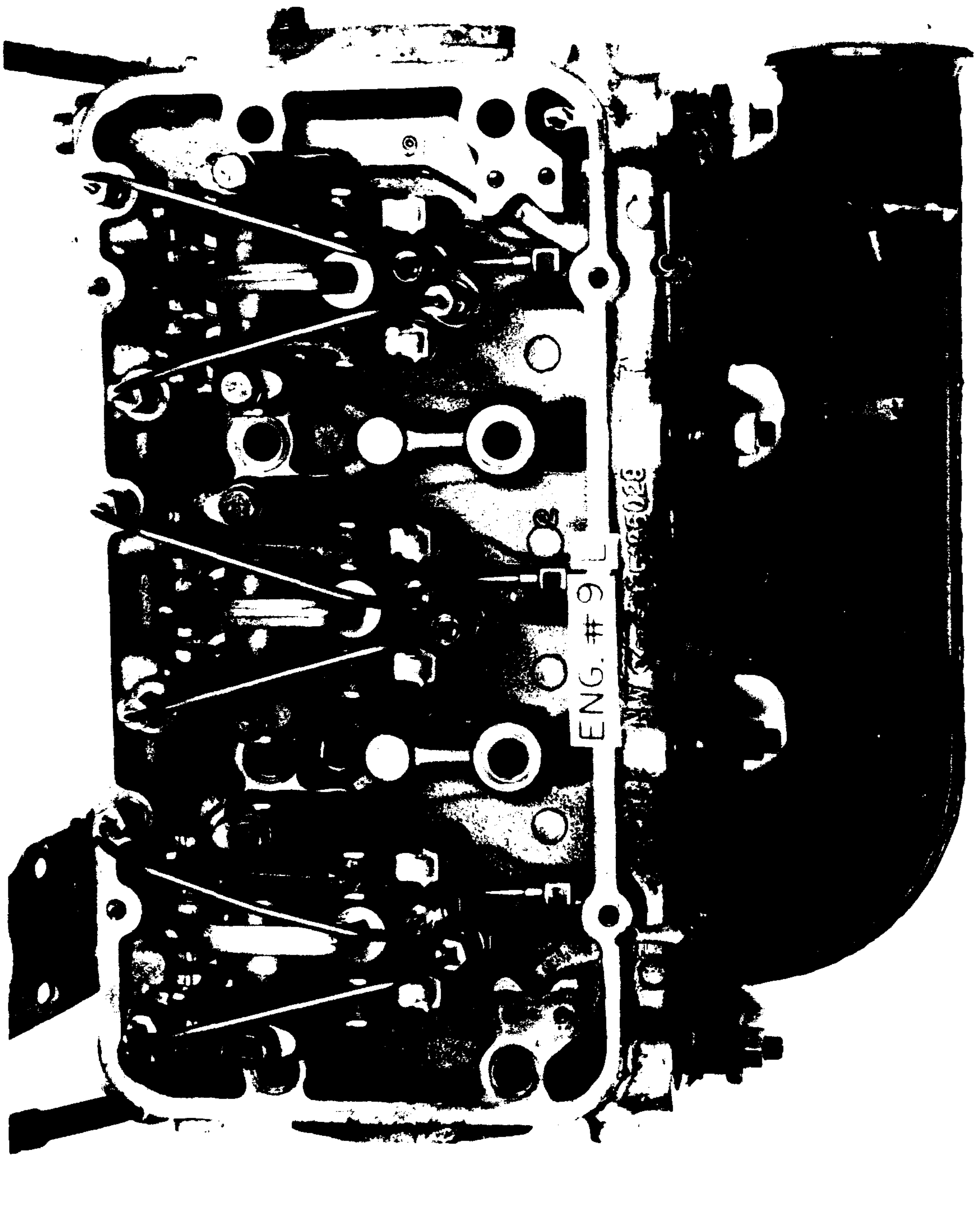
PEO



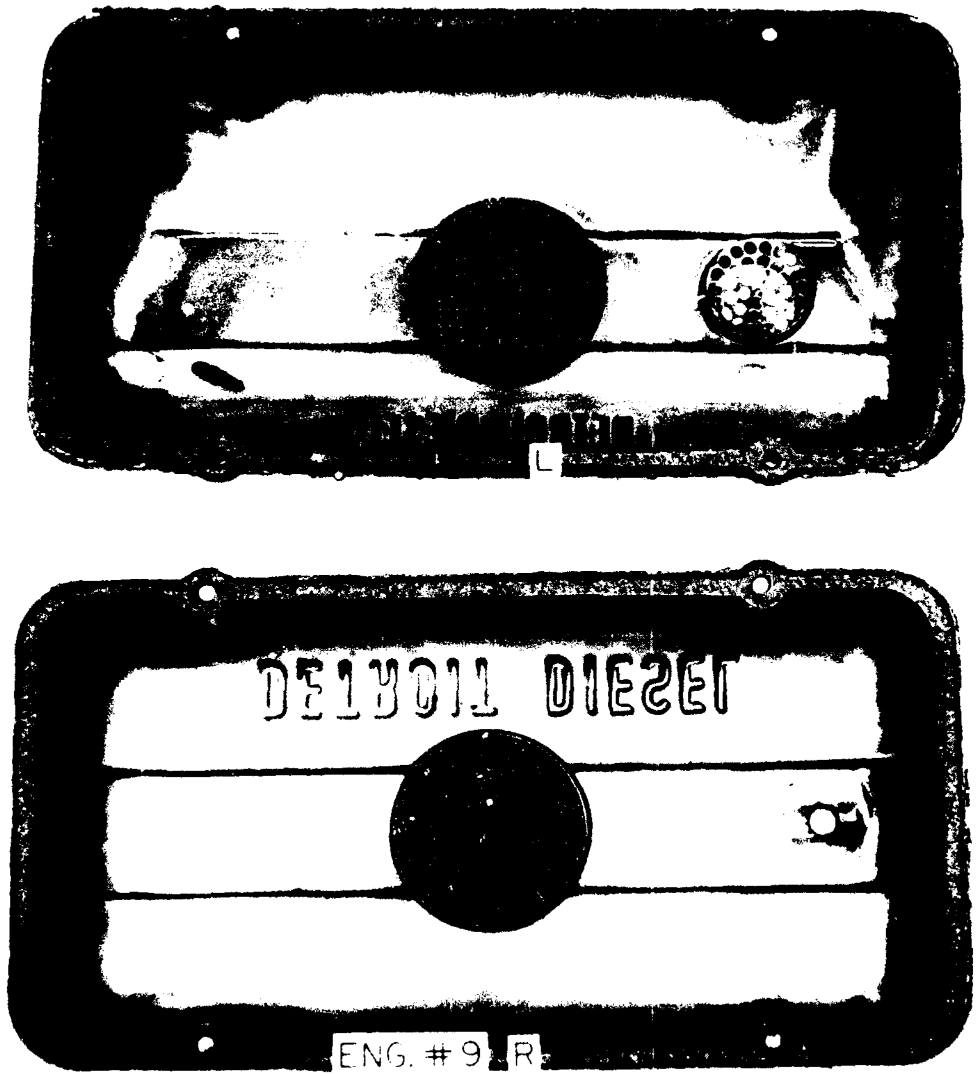
PEO



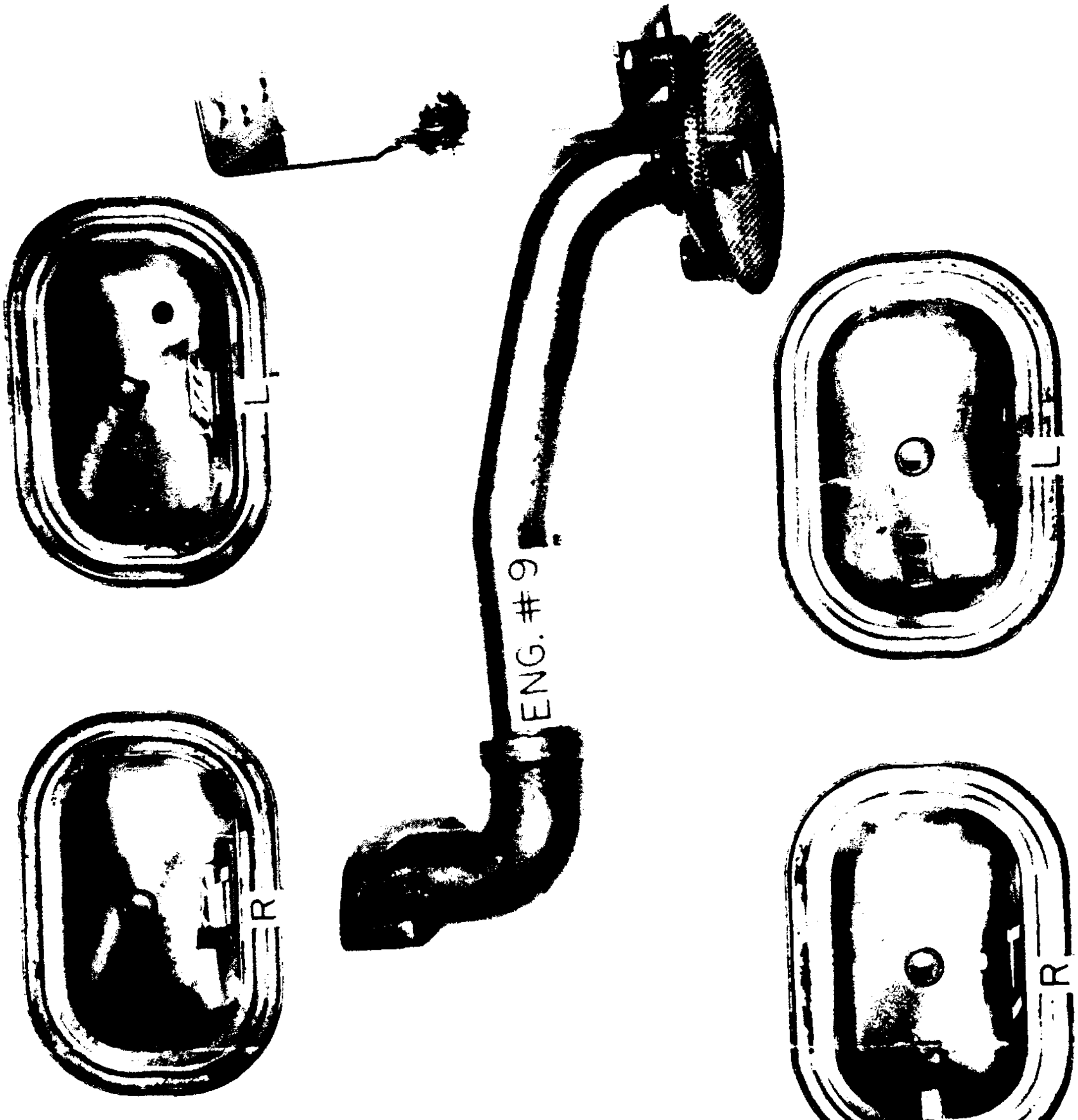
PEO + VCI-B



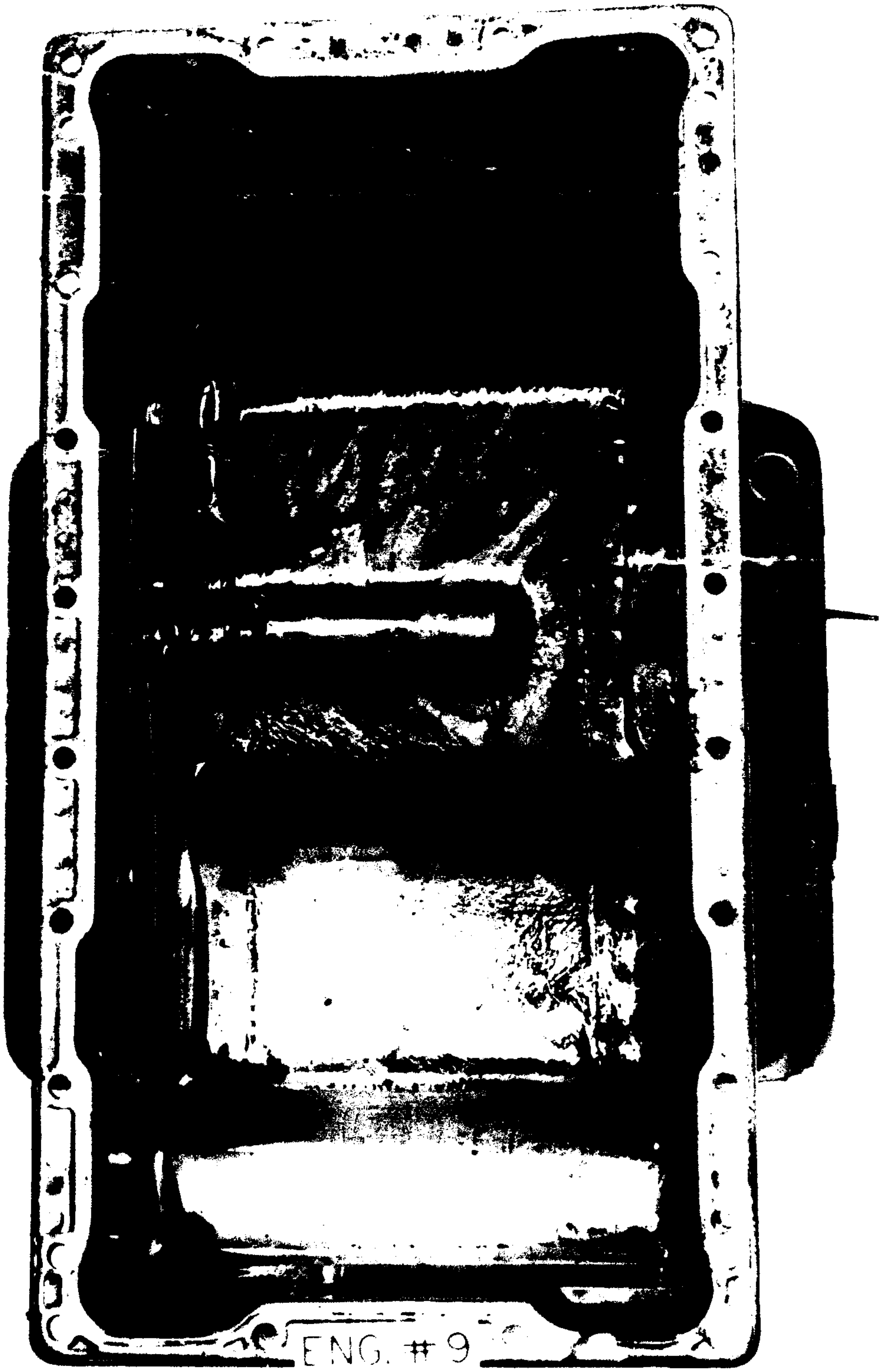
PEO + VCI-B



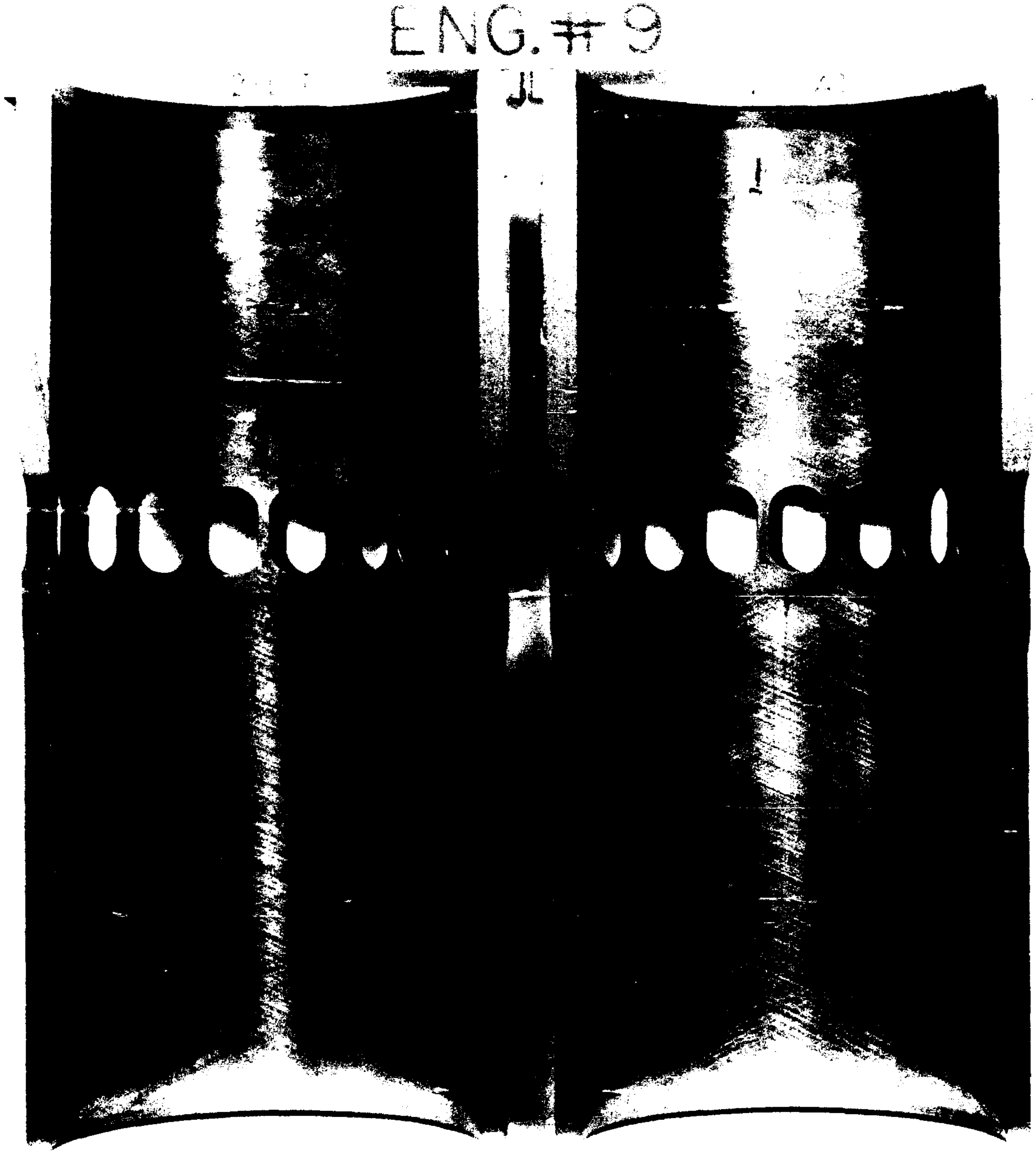
PEO + VCI-B



PEO + VCI-B

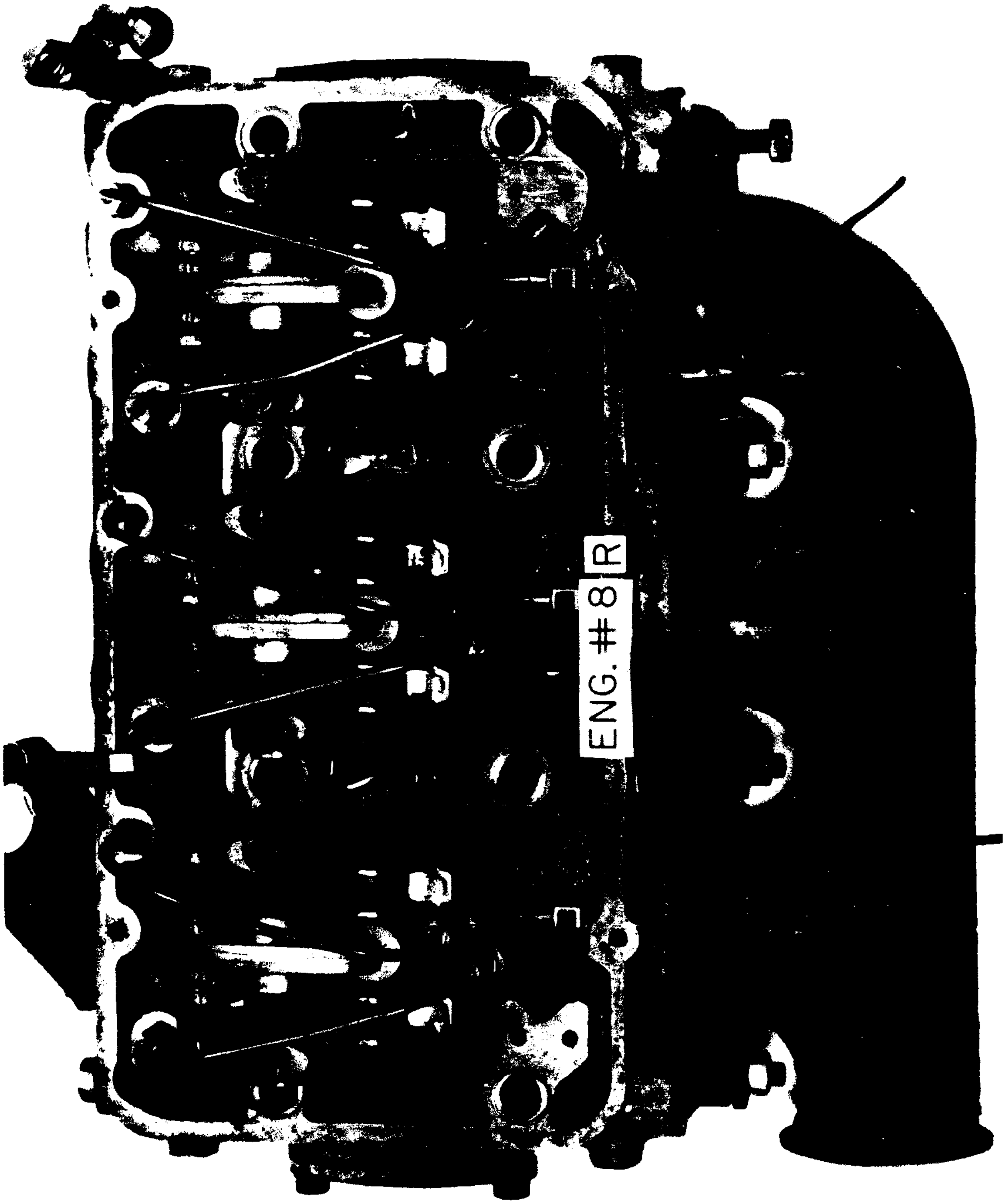


PEO + VCI-B

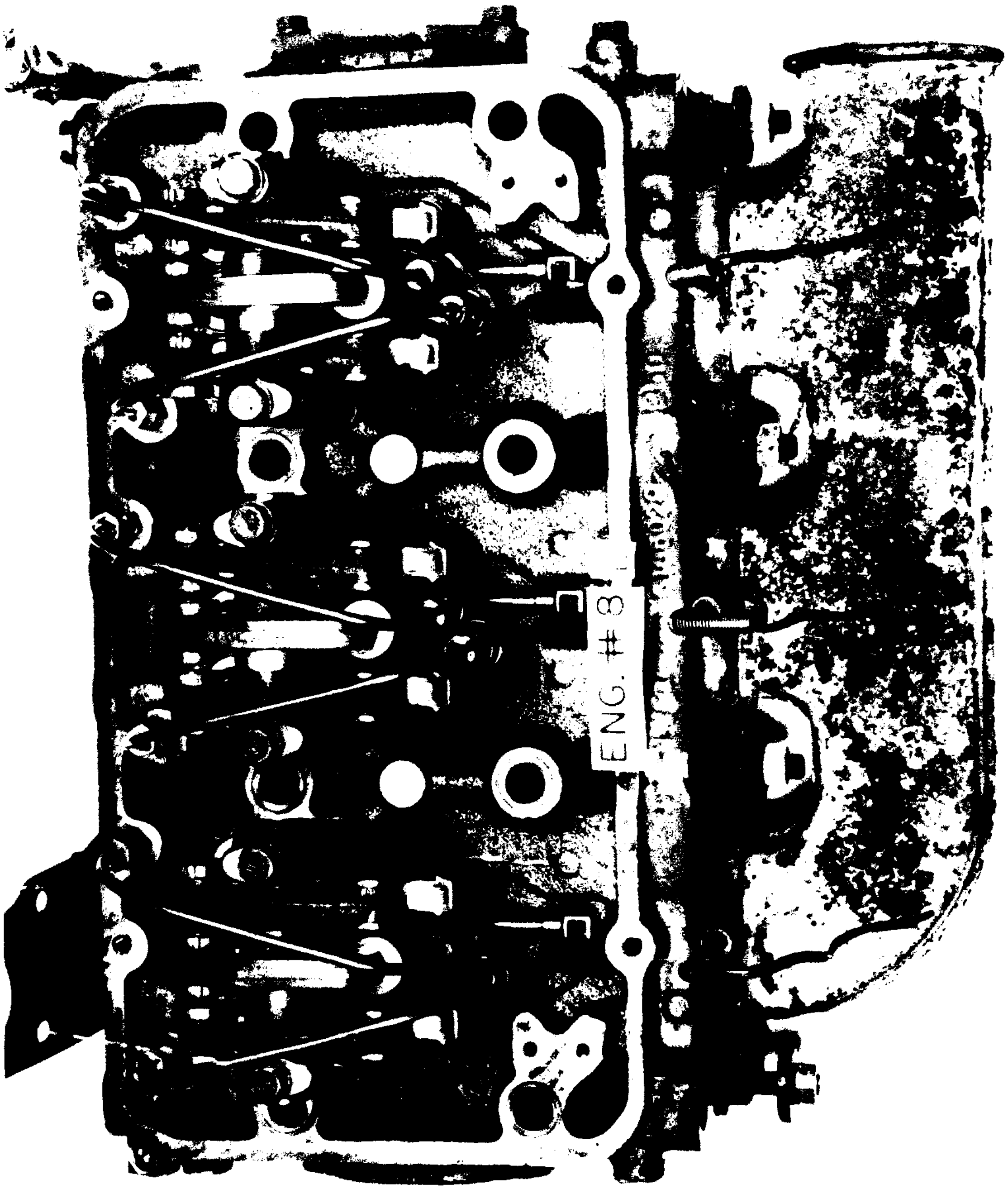


PEO + VCI-B

3-Year Storage



PEO



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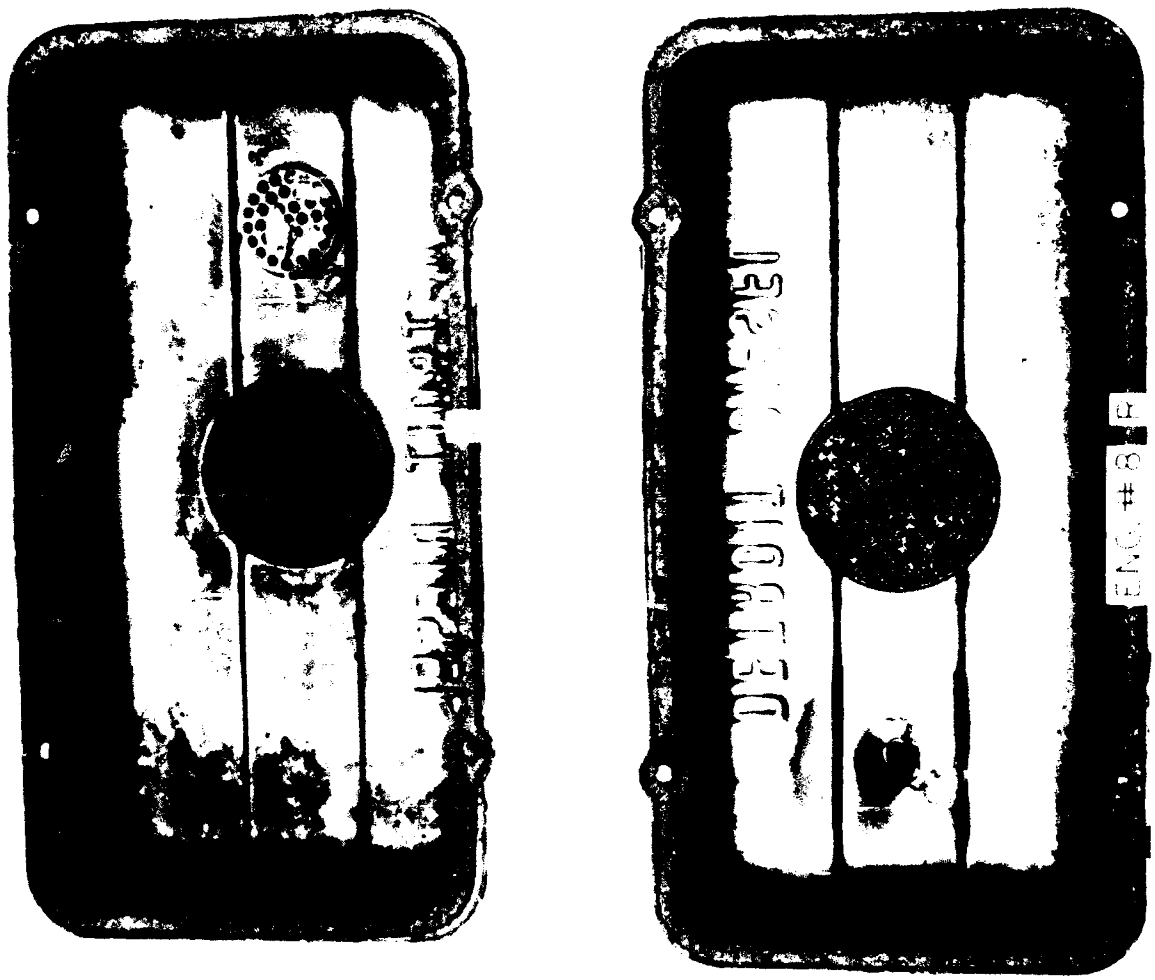

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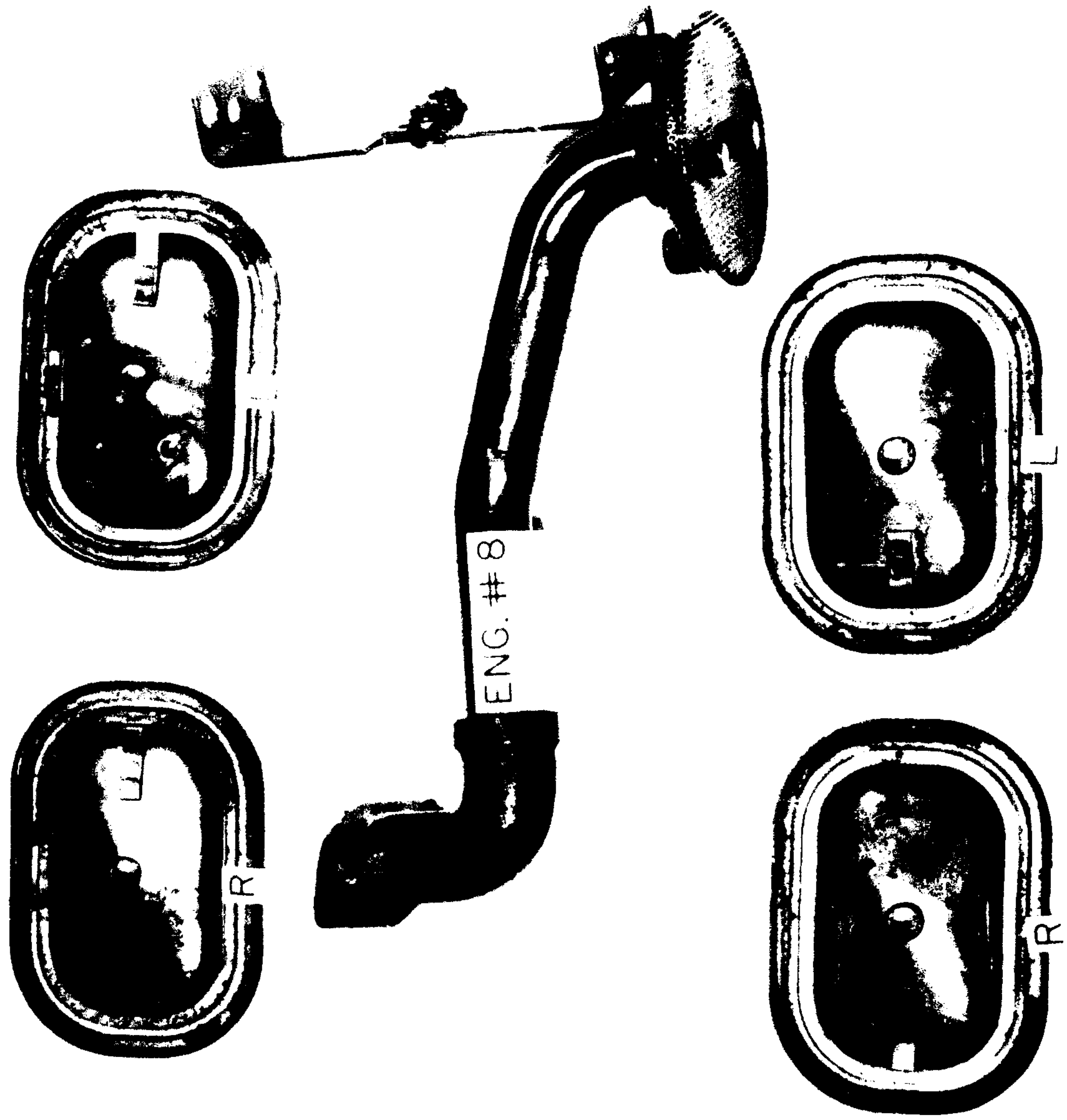

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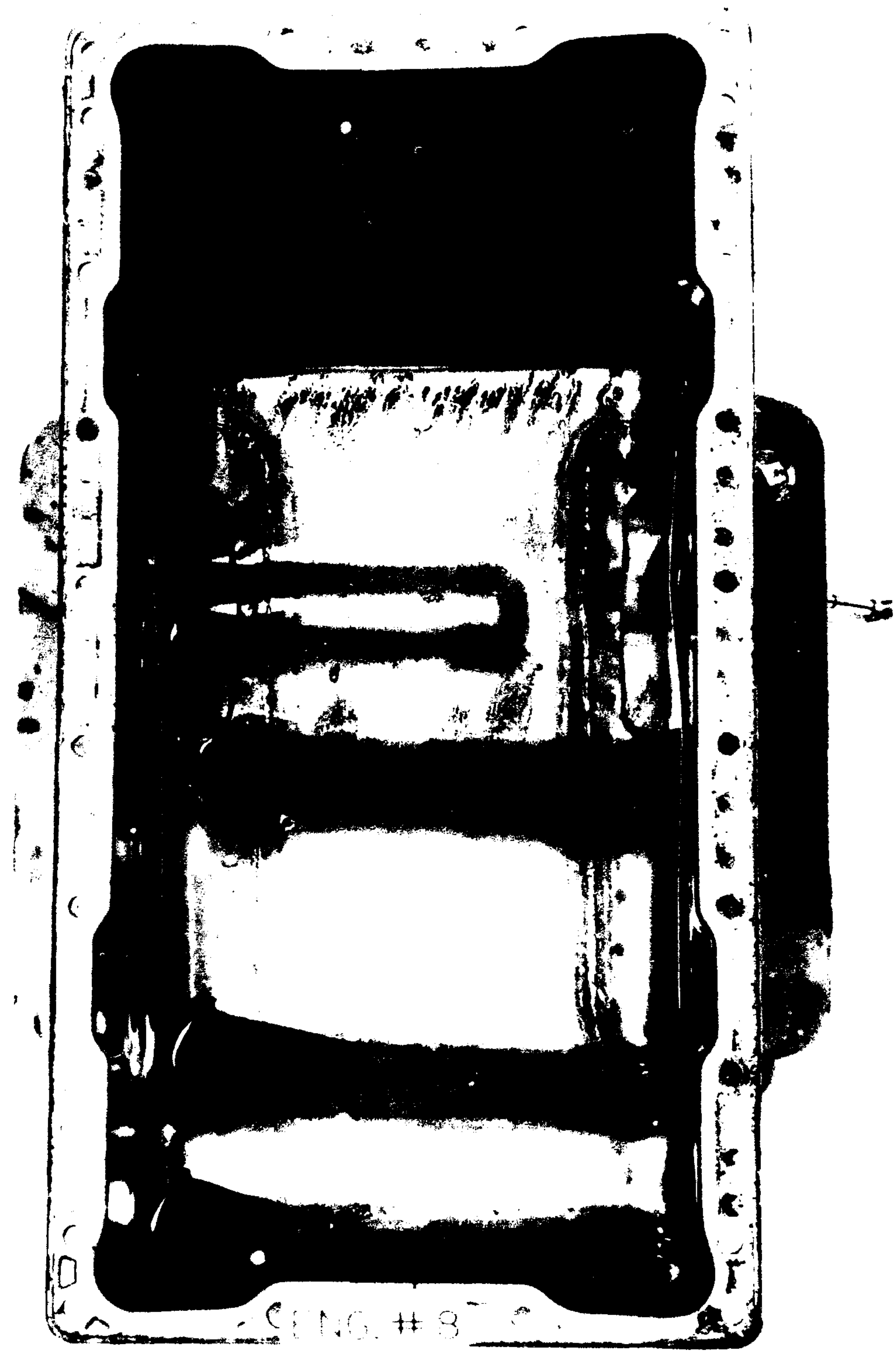

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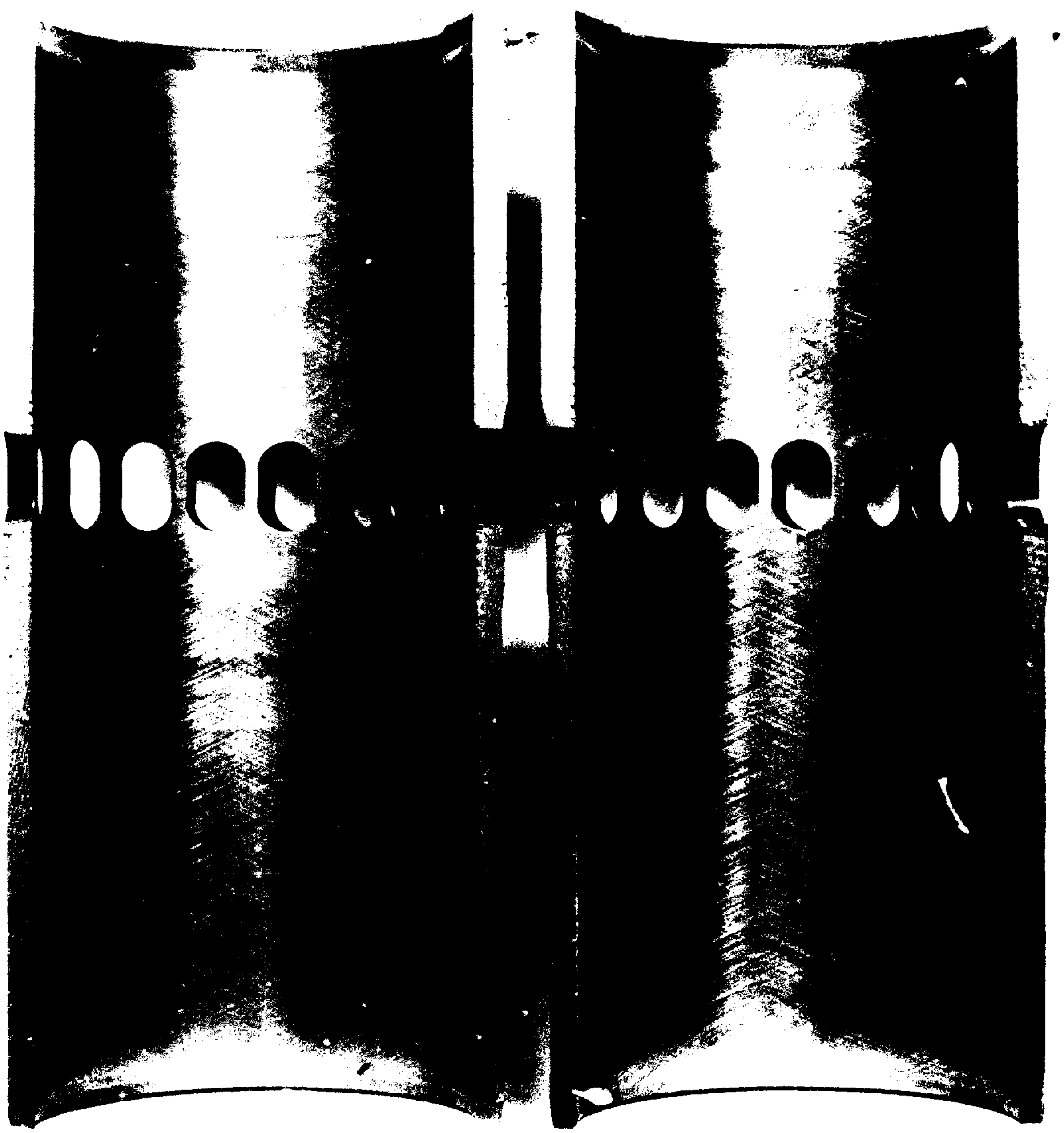
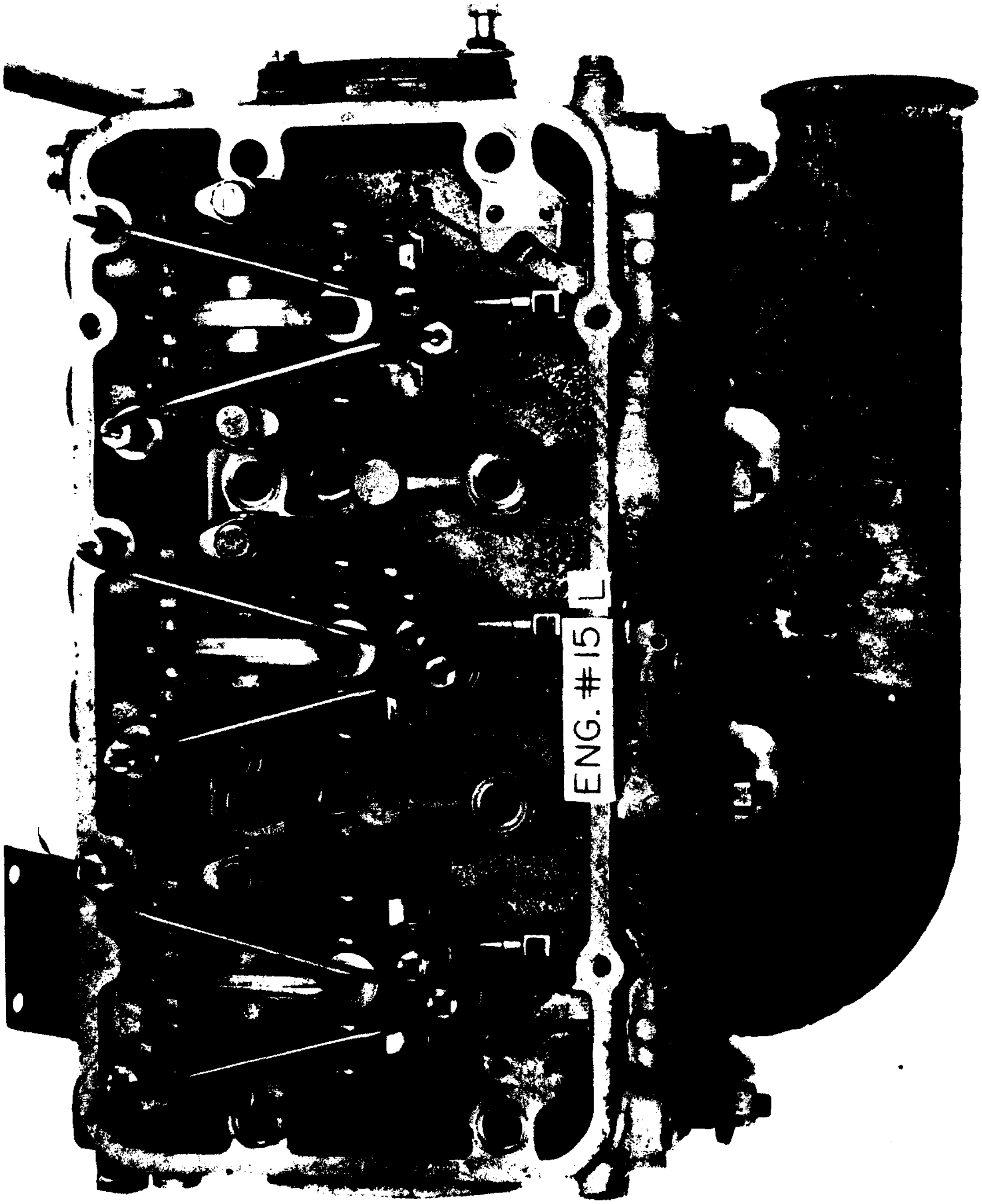


PEO

PEO + VCI-B



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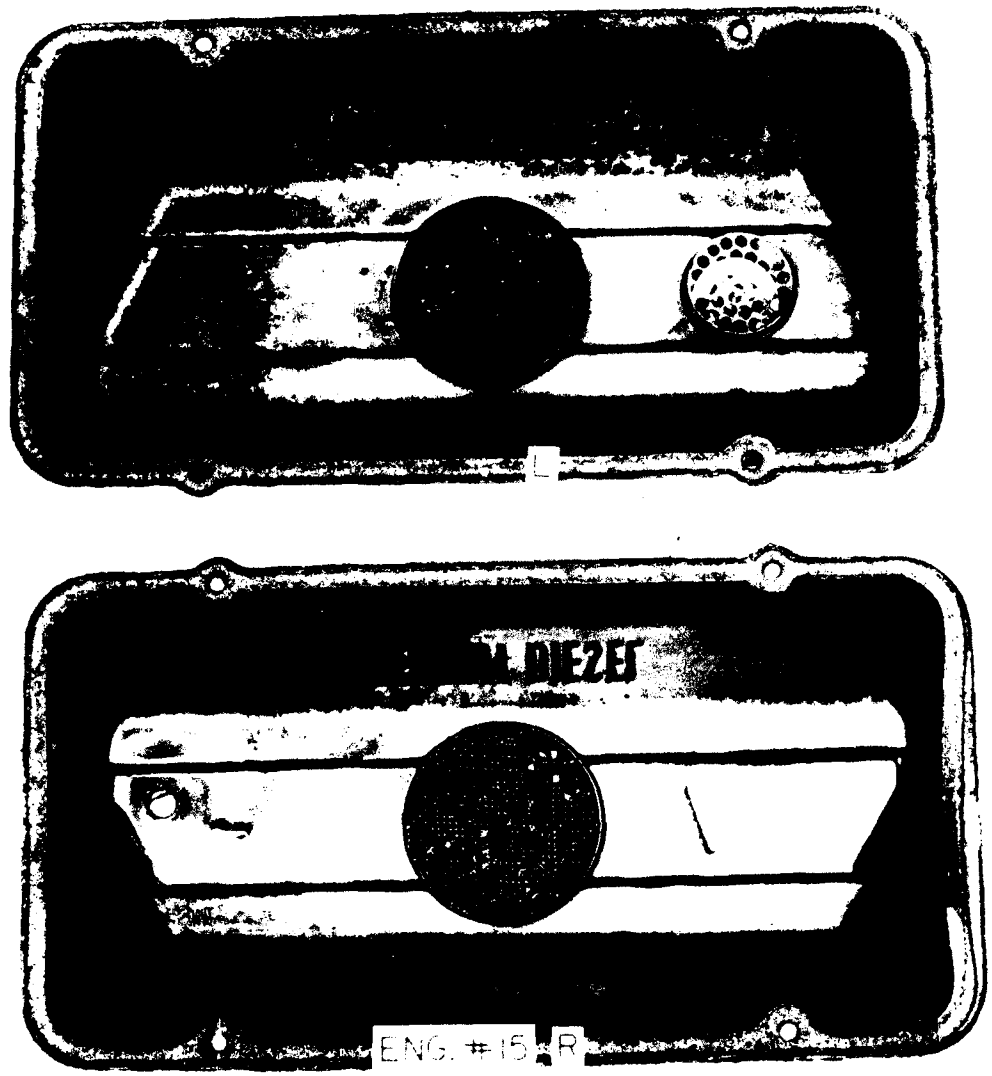

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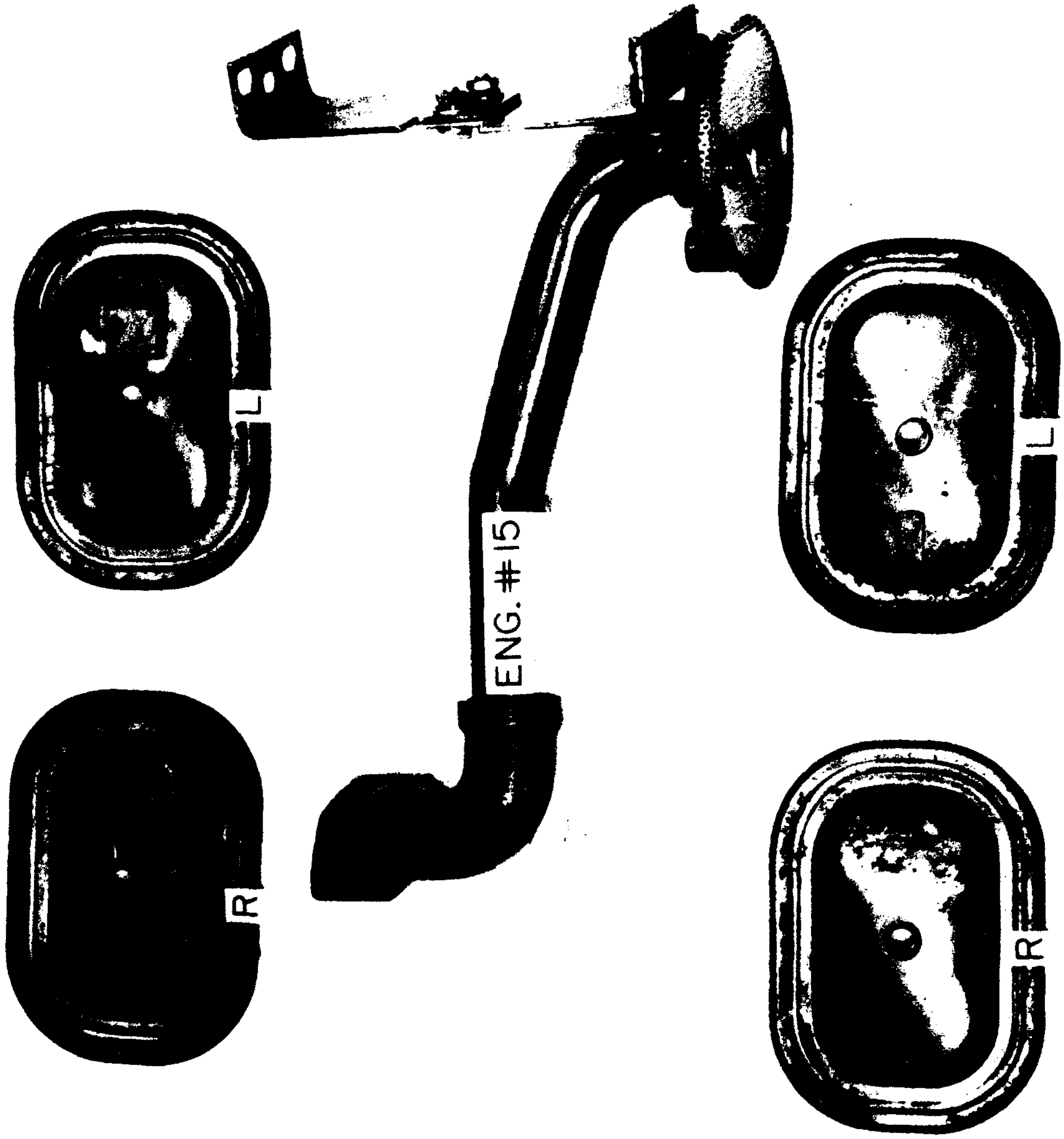

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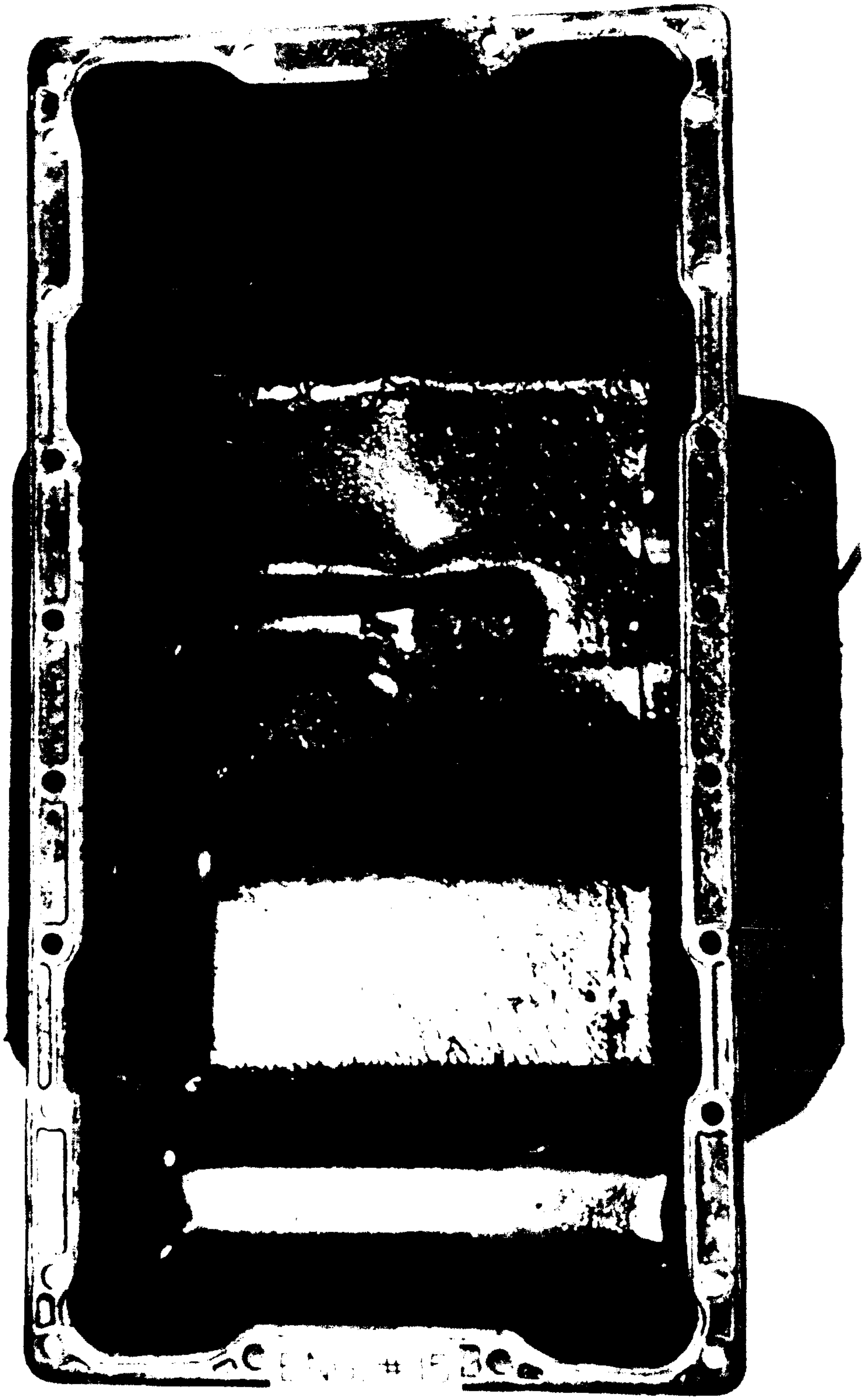
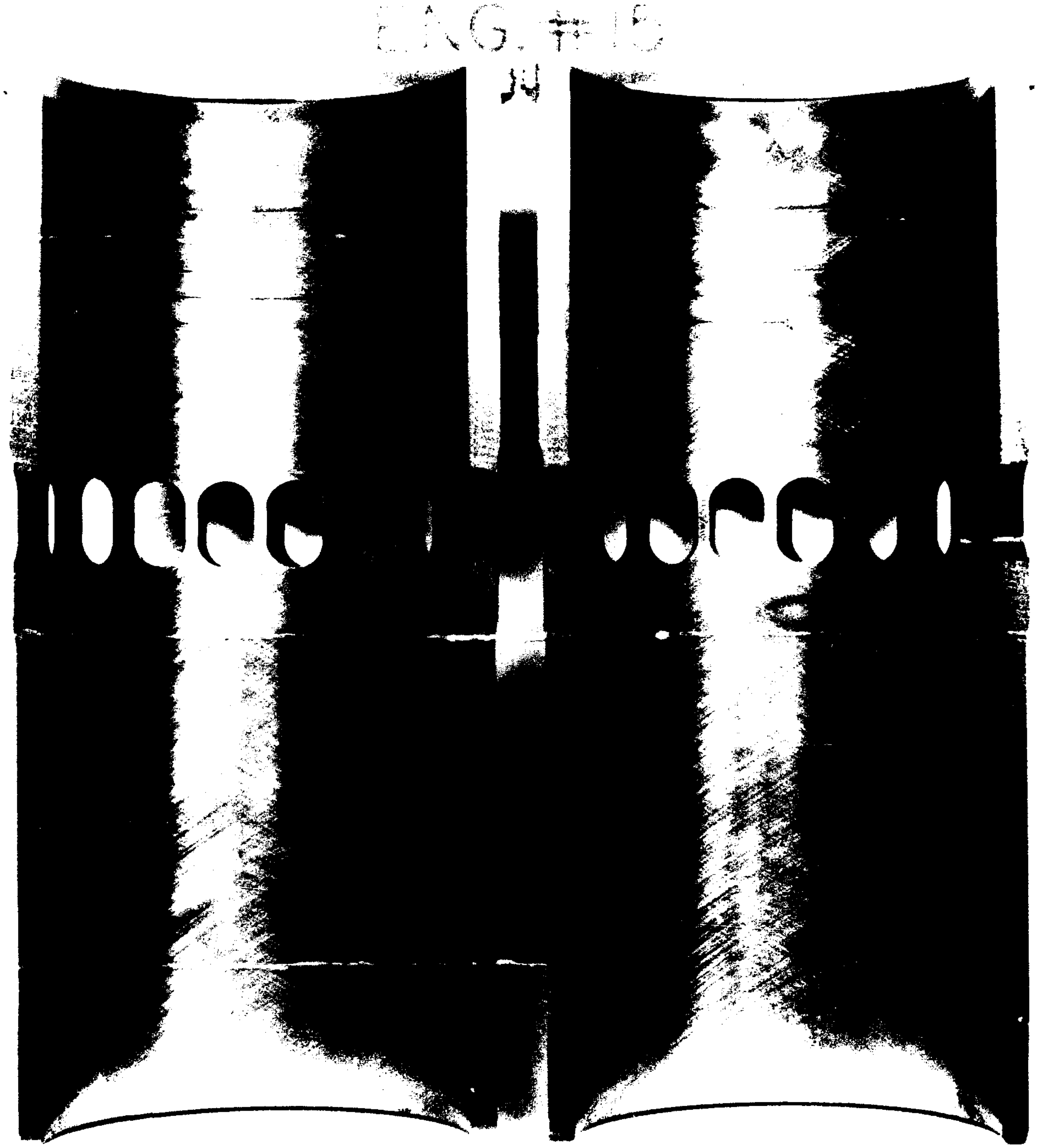


PEO + VCI-B

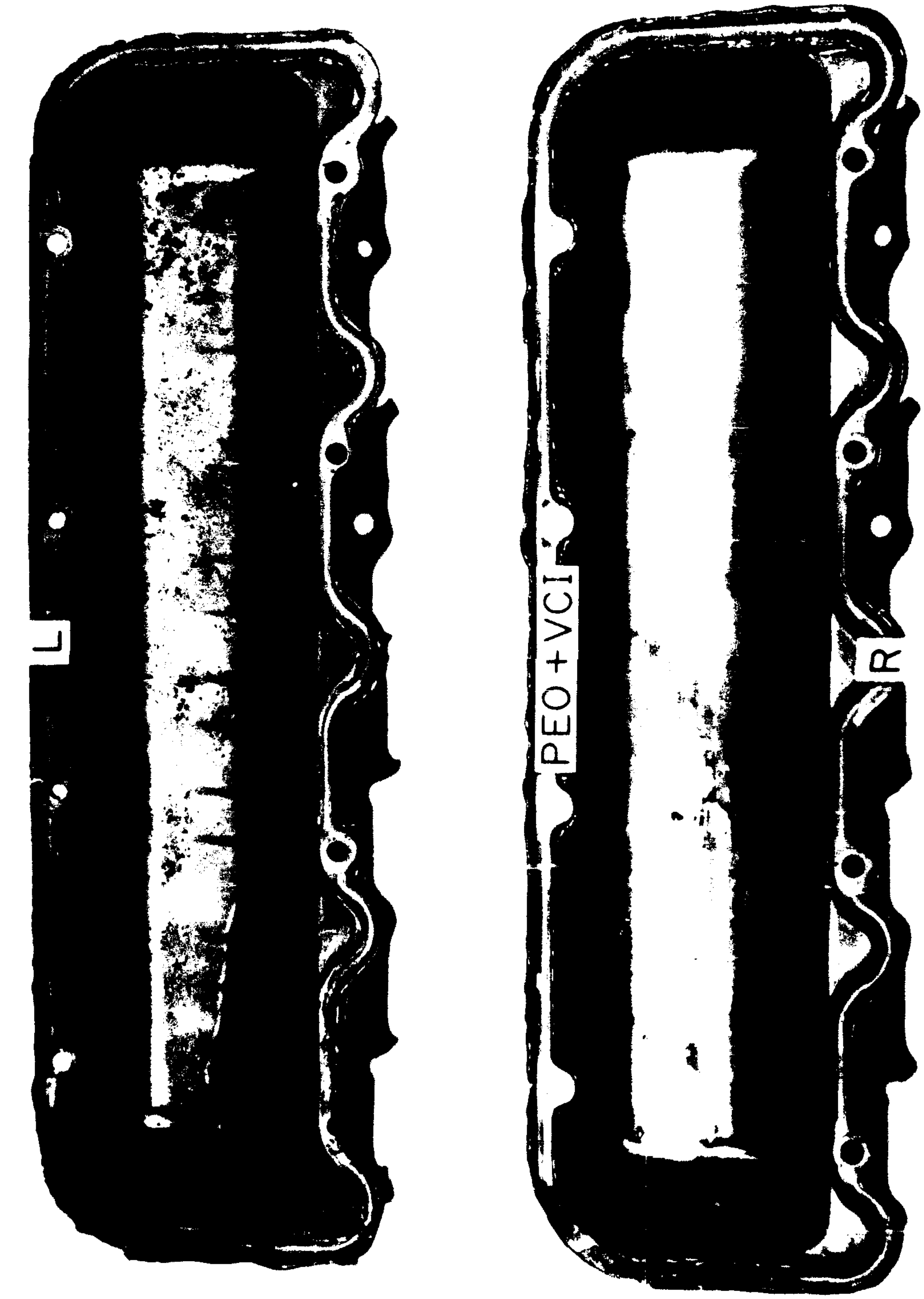


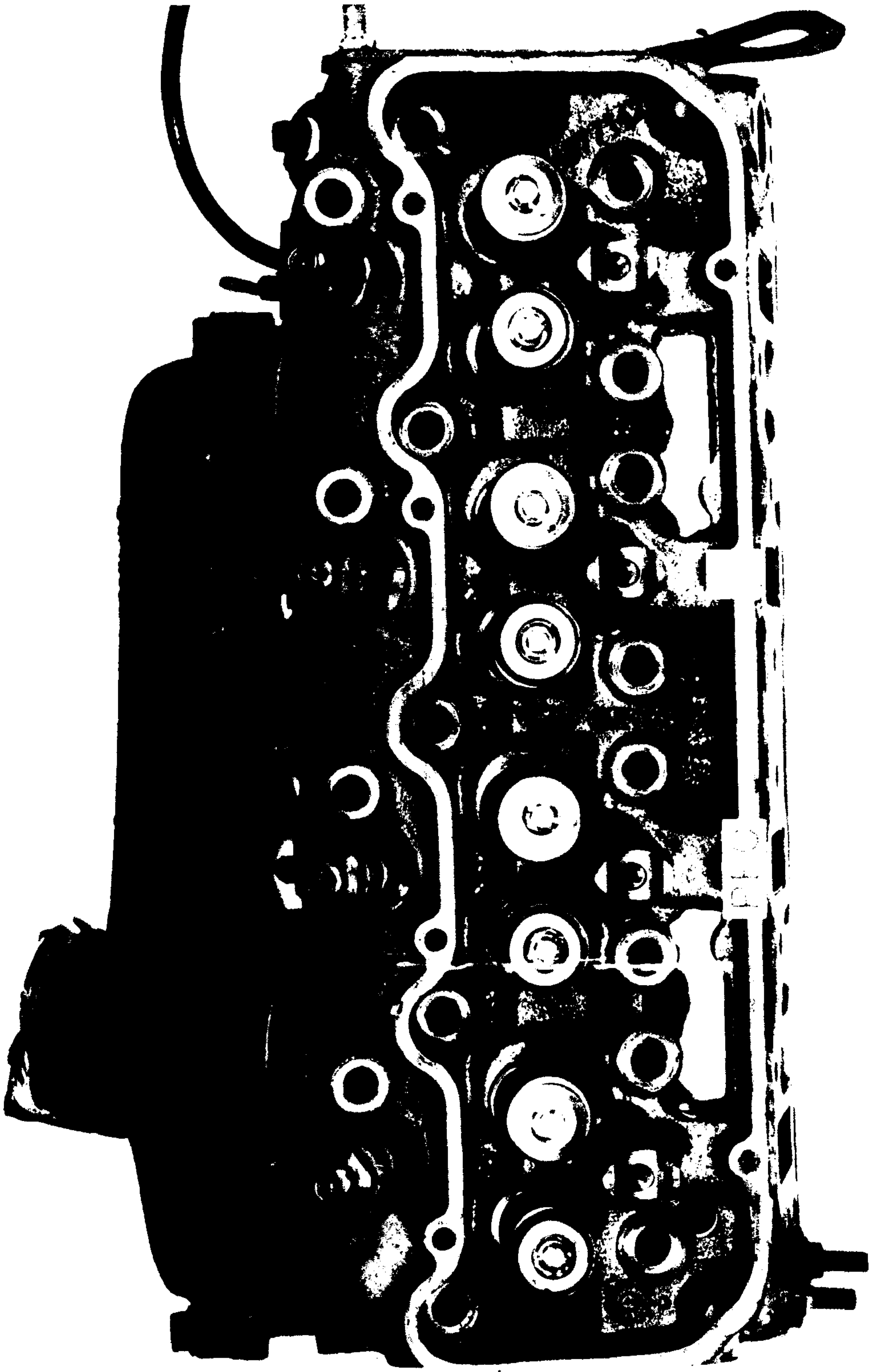
PEO + VCI-B

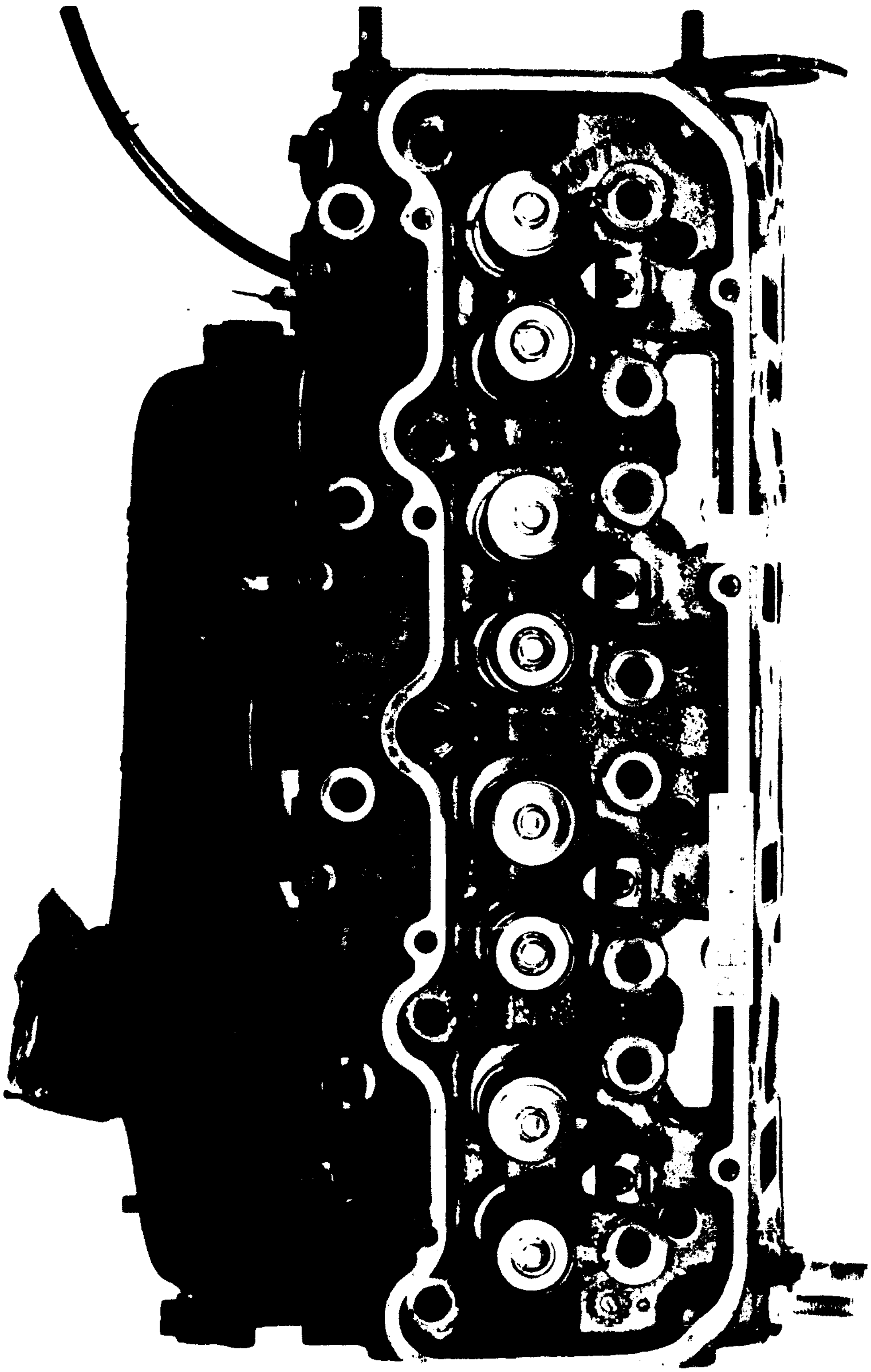
APPENDIX D

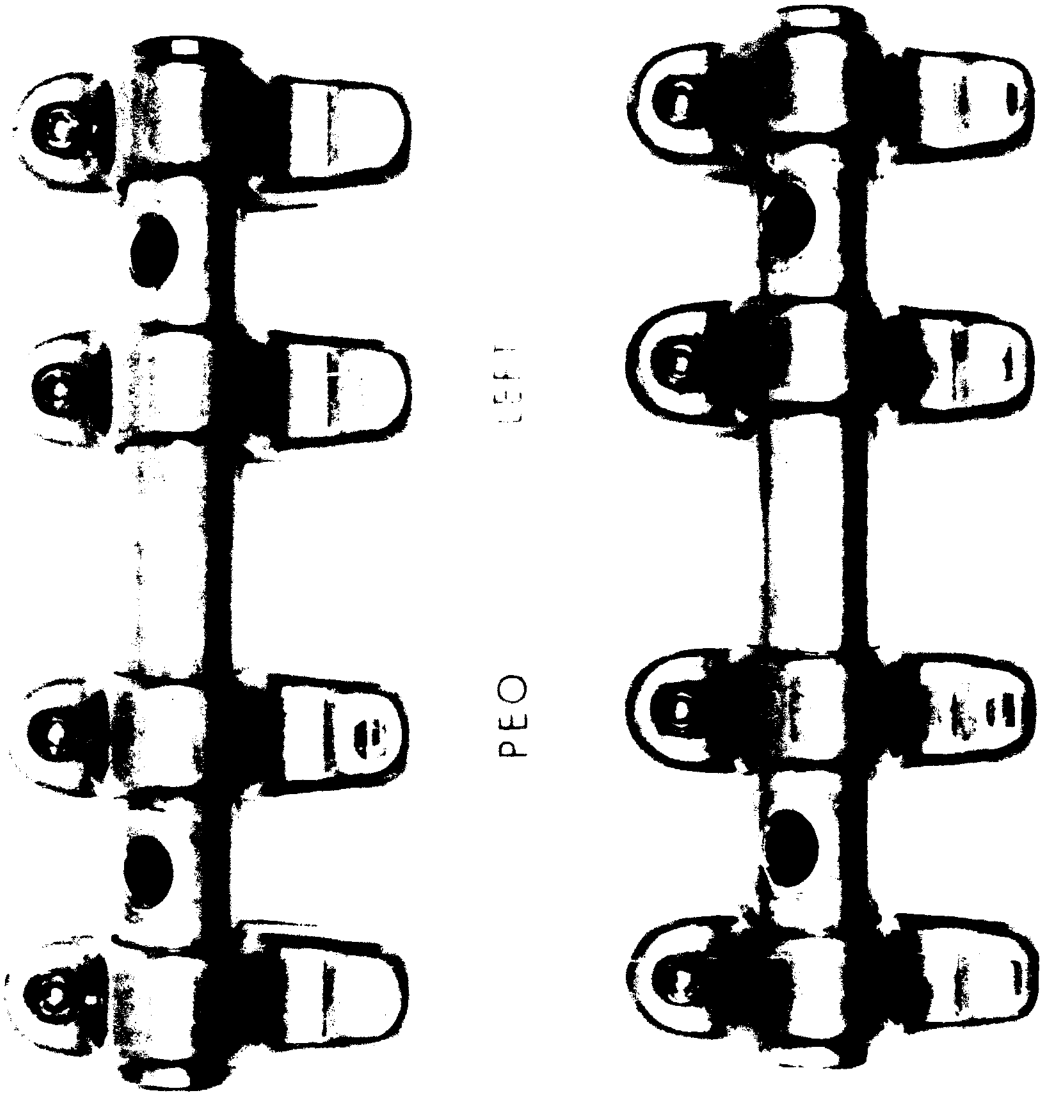
Photographs of GM 6.2L Engine Parts After 3-Year Storage


L
PEO
R


L
PEO + VCI
R



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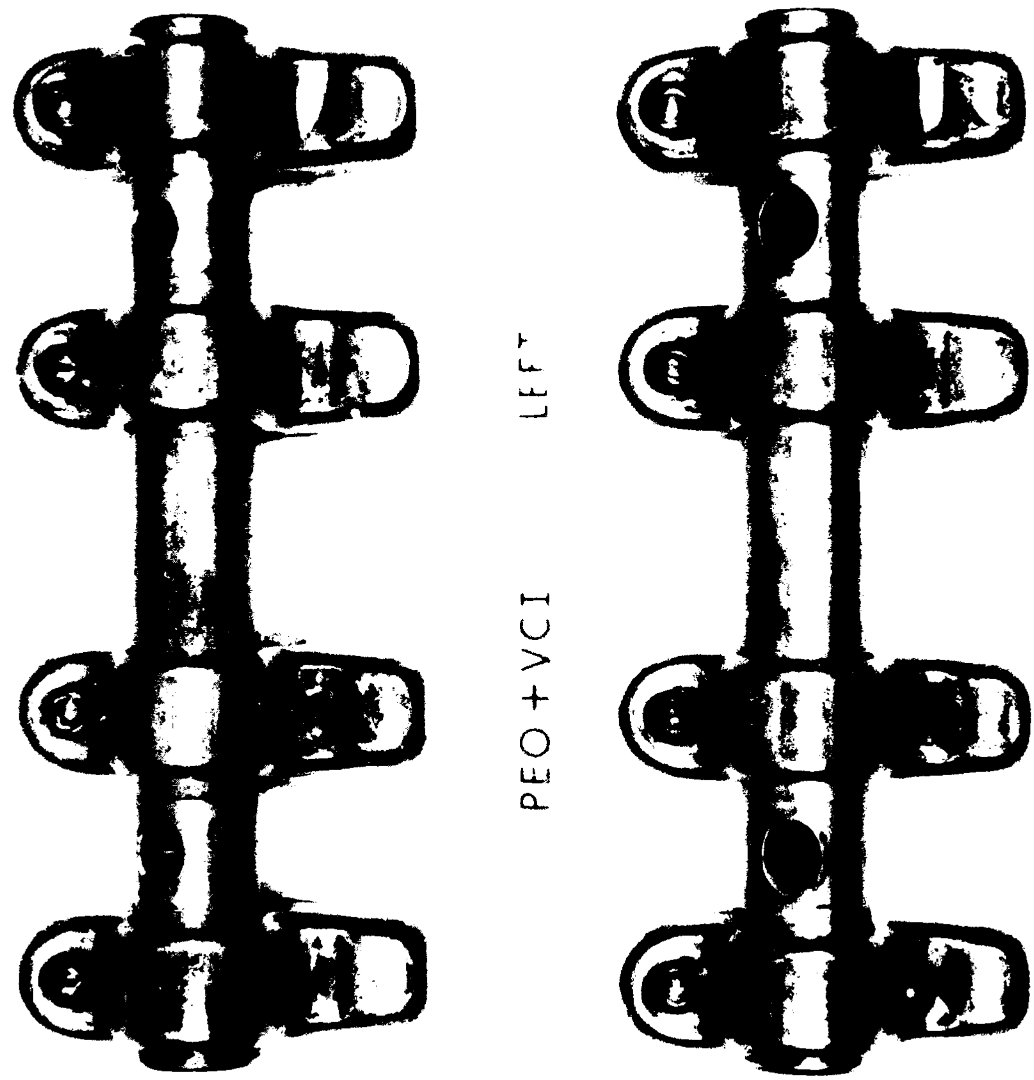
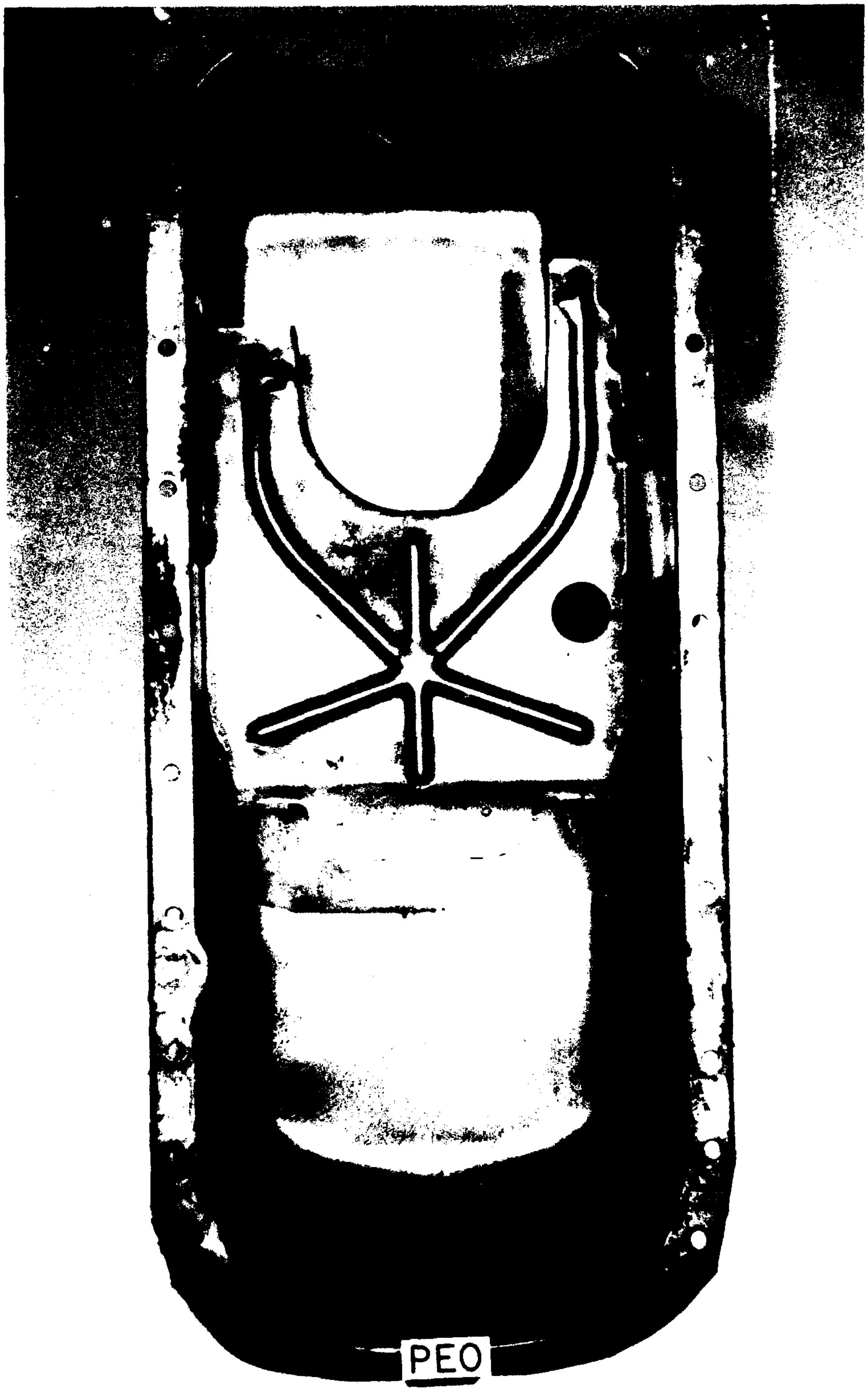
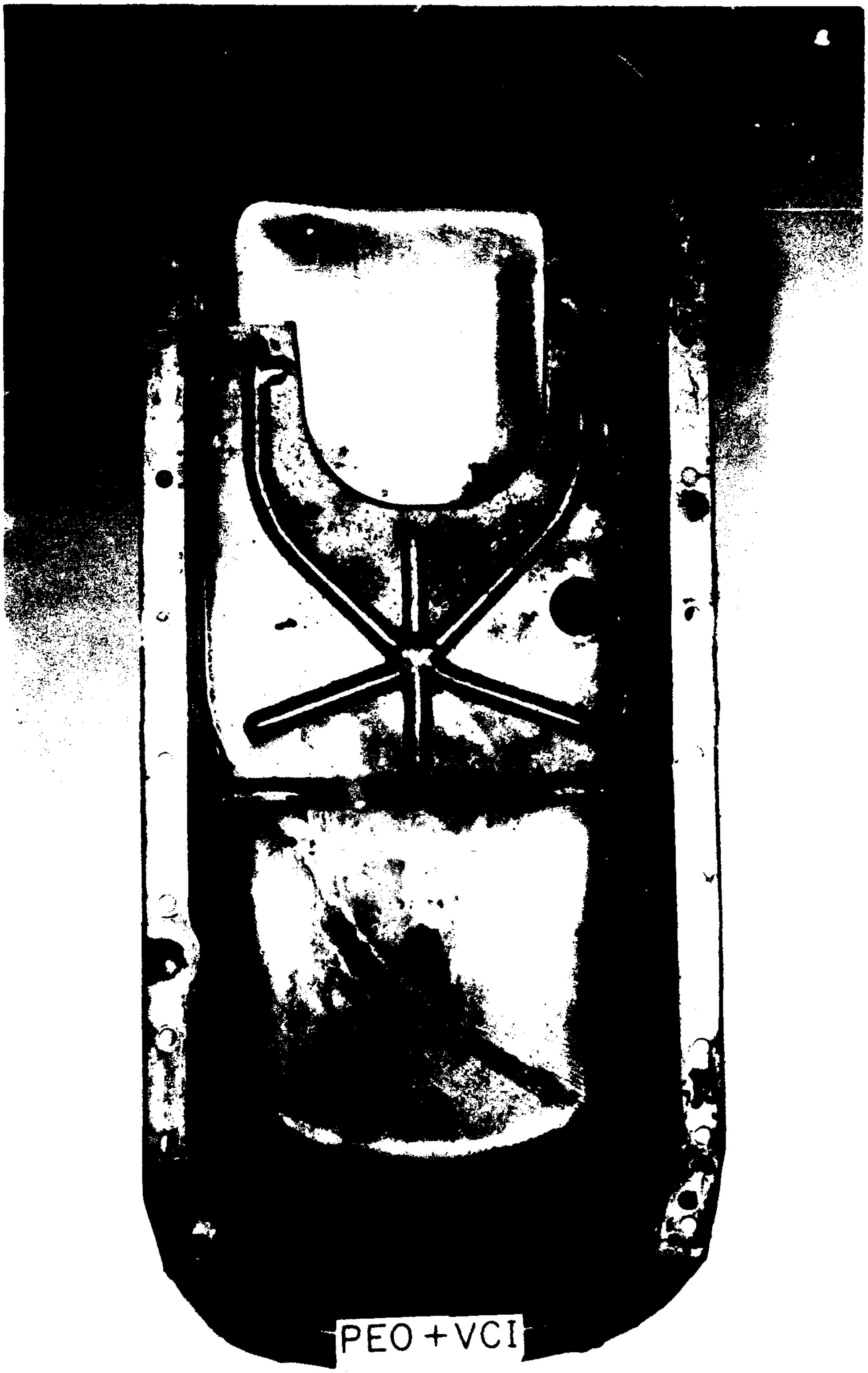
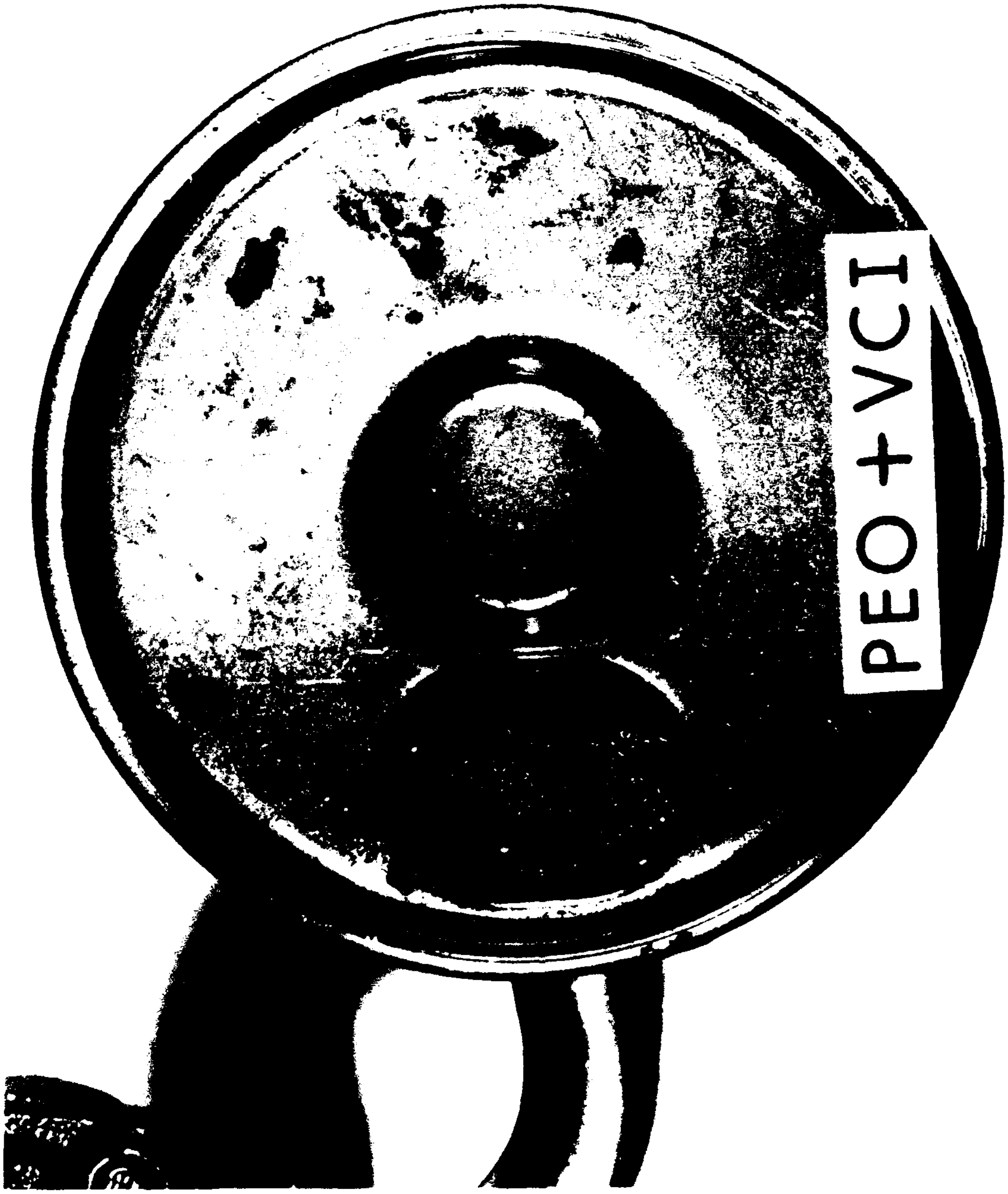

PEO + VCI
LEFT


PEO


PEO + VCI


PEO


PEO+VCI

APPENDIX E

Elastomer Storage Test Matrix

PUT ELASTOMERS IN CONTAINERS WITH 9 TO 1 LIQUID/SOLID RATIO

Polyester Urethanes

				Misc.	Misc.
4656 A	Air	1-year		--------	--------
4656 B	Air	2-year		--------	--------
4656 C	Air	3-year		--------	--------
4656 D	Neat	1-year	Submerged	--------	--------
4656 E	0.3 %	1-year	Submerged	--------	--------
4656 F	0.5%	1-year	Submerged	--------	--------
4656 G	0.7%	1-year	Submerged	--------	--------
4656 H	Mil-P-46002	1-year	Submerged	--------	--------
4656 I	Neat	1-year	Vapor	--------	--------
4656 J	0.3 %	1-year	Vapor	--------	--------
POLYESTER URETHANE K	0.5%	1-year	Vapor	--------	--------
POLYESTER URETHANE L	0.7%	1-year	Vapor	--------	--------
POLYESTER URETHANE M	Mil-P-46002	1-year	Vapor	--------	--------
POLYESTER URETHANE N	Neat	2-year	Submerged	--------	--------
POLYESTER URETHANE O	0.3 %	2-year	Submerged	--------	--------
POLYESTER URETHANE P	0.5%	2-year	Submerged	--------	--------
POLYESTER URETHANE Q	0.7%	2-year	Submerged	--------	--------
POLYESTER URETHANE R	Mil-P-46002	2-year	Submerged	--------	--------
POLYESTER URETHANE S	Neat	2-year	Vapor	--------	--------
POLYESTER URETHANE T	0.3 %	2-year	Vapor	--------	--------
POLYESTER URETHANE U	0.5%	2-year	Vapor	--------	--------
POLYESTER URETHANE V	0.7%	2-year	Vapor	--------	--------
POLYESTER URETHANE W	Mil-P-46002	2-year	Vapor	--------	--------
POLYESTER URETHANE X	Neat	3-year	Submerged	--------	--------
POLYESTER URETHANE Y	0.3 %	3-year	Submerged	--------	--------
POLYESTER URETHANE Z	0.5%	3-year	Submerged	--------	--------
POLYESTER URETHANE AA	0.7%	3-year	Submerged	--------	--------
POLYESTER URETHANE AB	Mil-P-46002	3-year	Submerged	--------	--------
POLYESTER URETHANE AC	Neat	3-year	Vapor	--------	--------
POLYESTER URETHANE AD	0.3 %	3-year	Vapor	--------	--------
POLYESTER URETHANE AE	0.5%	3-year	Vapor	--------	--------
POLYESTER URETHANE AF	0.7%	3-year	Vapor	--------	--------
POLYESTER URETHANE AG	Mil-P-46002	3-year	Vapor	--------	--------

Polyether Urethanes

P4661 A	Air	1-year		--------	--------
P4661 B	Air	2-year		--------	--------
P4661 C	Air	3-Year		--------	--------
P4661 D	Neat	1-year	Submerged	--------	--------
P4661 E	0.3 %	1-year	Submerged	--------	--------
P4661 F	0.5%	1-year	Submerged	--------	--------
P4661 G	0.7%	1-year	Submerged	--------	--------
P4661 H	Mil-P-46002	1-year	Submerged	--------	--------
P4661 I	Neat	1-year	Vapor	--------	--------
P4661 J	0.3 %	1-year	Vapor	--------	--------
POLYETHER URETHANE K	0.5%	1-year	Vapor	--------	--------
POLYETHER URETHANE L	0.7%	1-year	Vapor	--------	--------
POLYETHER URETHANE M	Mil-P-46002	1-year	Vapor	--------	--------
POLYETHER URETHANE N	Neat	2-year	Submerged	--------	--------
POLYETHER URETHANE O	0.3 %	2-year	Submerged	--------	--------
POLYETHER URETHANE P	0.5%	2-year	Submerged	--------	--------
POLYETHER URETHANE Q	0.7%	2-year	Submerged	--------	--------
POLYETHER URETHANE R	Mil-P-46002	2-year	Submerged	--------	--------
POLYETHER URETHANE S	Neat	2-year	Vapor	--------	--------
POLYETHER URETHANE T	0.3 %	2-year	Vapor	--------	--------
POLYETHER URETHANE U	0.5%	2-year	Vapor	--------	--------
POLYETHER URETHANE V	0.7%	2-year	Vapor	--------	--------
POLYETHER URETHANE W	Mil-P-46002	2-year	Vapor	--------	--------
POLYETHER URETHANE X	Neat	3-year	Submerged	--------	--------
POLYETHER URETHANE Y	0.3 %	3-year	Submerged	--------	--------
POLYETHER URETHANE Z	0.5%	3-year	Submerged	--------	--------
POLYETHER URETHANE AA	0.7%	3-year	Submerged	--------	--------
POLYETHER URETHANE AB	Mil-P-46002	3-year	Submerged	--------	--------
POLYETHER URETHANE AC	Neat	3-year	Vapor	--------	--------
POLYETHER URETHANE AD	0.3 %	3-year	Vapor	--------	--------
POLYETHER URETHANE AE	0.5%	3-year	Vapor	--------	--------
POLYETHER URETHANE AF	0.7%	3-year	Vapor	--------	--------
POLYETHER URETHANE AG	Mil-P-46002	3-year	Vapor	--------	--------

HIGH NITRILE

5617 A	Air	1-Year		--------	--------
5617 B	Air	2-year		--------	--------
5617 C	Air	3-year		--------	--------
5617 D	Neat	1-year	Submerged	--------	--------
5617 E	0.3 %	1-year	Submerged	--------	--------
5617 F	0.5%	1-year	Submerged	--------	--------
5617 G	0.7%	1-year	Submerged	--------	--------
5617 H	Mil-F-46002	1-year	Submerged	--------	--------
5617 I	Neat	1-year	Vapor	--------	--------
5617 J	0.3 %	1-year	Vapor	--------	--------
HIGH NITRILE K	0.5%	1-year	Vapor	--------	--------
HIGH NITRILE L	0.7%	1-year	Vapor	--------	--------
HIGH NITRILE M	Mil-F-46002	1-year	Vapor	--------	--------
HIGH NITRILE N	Neat	2-year	Submerged	--------	--------
HIGH NITRILE O	0.3 %	2-year	Submerged	--------	--------
HIGH NITRILE P	0.5%	2-year	Submerged	--------	--------
HIGH NITRILE Q	0.7%	2-year	Submerged	--------	--------
HIGH NITRILE R	Mil-F-46002	2-year	Submerged	--------	--------
HIGH NITRILE S	Neat	2-year	Vapor	--------	--------
HIGH NITRILE T	0.3 %	2-year	Vapor	--------	--------
HIGH NITRILE U	0.5%	2-year	Vapor	--------	--------
HIGH NITRILE V	0.7%	2-year	Vapor	--------	--------
HIGH NITRILE W	Mil-F-46002	2-year	Vapor	--------	--------
HIGH NITRILE X	Neat	3-year	Submerged	--------	--------
HIGH NITRILE Y	0.3 %	3-year	Submerged	--------	--------
HIGH NITRILE Z	0.5%	3-year	Submerged	--------	--------
HIGH NITRILE AA	0.7%	3-year	Submerged	--------	--------
HIGH NITRILE AB	Mil-F-46002	3-year	Submerged	--------	--------
HIGH NITRILE AC	Neat	3-year	Vapor	--------	--------
HIGH NITRILE AD	0.3 %	3-year	Vapor	--------	--------
HIGH NITRILE AE	0.5%	3-year	Vapor	--------	--------
HIGH NITRILE AF	0.7%	3-year	Vapor	--------	--------
HIGH NITRILE AG	Mil-F-46002	3-year	Vapor	--------	--------

MEDIUM NITRILE

5616 A	Air	1-Year		--------	--------
5616 B	Air	2-year		--------	--------
5616 C	Air	3-Year		--------	--------
5616 D	Neat	1-year	Submerged	--------	--------
5616 E	0.3 %	1-year	Submerged	--------	--------
5616 F	0.5%	1-year	Submerged	--------	--------
5616 G	0.7%	1-year	Submerged	--------	--------
5616 H	Mil-F-46002	1-year	Submerged	--------	--------
5616 I	Neat	1-year	Vapor	--------	--------
5616 J	0.3 %	1-year	Vapor	--------	--------
MEDIUM NITRILE K	0.5%	1-year	Vapor	--------	--------
MEDIUM NITRILE L	0.7%	1-year	Vapor	--------	--------
MEDIUM NITRILE M	Mil-F-46002	1-year	Vapor	--------	--------
MEDIUM NITRILE N	Neat	2-year	Submerged	--------	--------
MEDIUM NITRILE O	0.3 %	2-year	Submerged	--------	--------
MEDIUM NITRILE P	0.5%	2-year	Submerged	--------	--------
MEDIUM NITRILE Q	0.7%	2-year	Submerged	--------	--------
MEDIUM NITRILE R	Mil-F-46002	2-year	Submerged	--------	--------
MEDIUM NITRILE S	Neat	2-year	Vapor	--------	--------
MEDIUM NITRILE T	0.3 %	2-year	Vapor	--------	--------
MEDIUM NITRILE U	0.5%	2-year	Vapor	--------	--------
MEDIUM NITRILE V	0.7%	2-year	Vapor	--------	--------
MEDIUM NITRILE W	Mil-F-46002	2-year	Vapor	--------	--------
MEDIUM NITRILE X	Neat	3-year	Submerged	--------	--------
MEDIUM NITRILE Y	0.3 %	3-year	Submerged	--------	--------
MEDIUM NITRILE Z	0.5%	3-year	Submerged	--------	--------
MEDIUM NITRILE AA	0.7%	3-year	Submerged	--------	--------
MEDIUM NITRILE AB	Mil-F-46002	3-year	Submerged	--------	--------
MEDIUM NITRILE AC	Neat	3-year	Vapor	--------	--------
MEDIUM NITRILE AD	0.3 %	3-year	Vapor	--------	--------
MEDIUM NITRILE AE	0.5%	3-year	Vapor	--------	--------
MEDIUM NITRILE AF	0.7%	3-year	Vapor	--------	--------
MEDIUM NITRILE AG	Mil-F-46002	3-year	Vapor	--------	--------

LOW NITRILE

5618 A	Air	1-year		--------	--------
5618 B	Air	2-year		--------	--------
5618 C	Air	3-Year		--------	--------
5618 D	Neat	1-year	Submerged	--------	--------
5618 E	0.3 %	1-year	Submerged	--------	--------
5618 F	0.5%	1-year	Submerged	--------	--------
5618 G	0.7%	1-year	Submerged	--------	--------
5618 H	Mil-P-46002	1-year	Submerged	--------	--------
5618 I	Neat	1-year	Vapor	--------	--------
5618 J	0.3 %	1-year	Vapor	--------	--------
LOW NITRILE K	0.5%	1-year	Vapor	--------	--------
LOW NITRILE L	0.7%	1-year	Vapor	--------	--------
LOW NITRILE M	Mil-P-46002	1-year	Vapor	--------	--------
LOW NITRILE N	Neat	2-year	Submerged	--------	--------
LOW NITRILE O	0.3 %	2-year	Submerged	--------	--------
LOW NITRILE P	0.5%	2-year	Submerged	--------	--------
LOW NITRILE Q	0.7%	2-year	Submerged	--------	--------
LOW NITRILE R	Mil-P-46002	2-year	Submerged	--------	--------
LOW NITRILE S	Neat	2-year	Vapor	--------	--------
LOW NITRILE T	0.3 %	2-year	Vapor	--------	--------
LOW NITRILE U	0.5%	2-year	Vapor	--------	--------
LOW NITRILE V	0.7%	2-year	Vapor	--------	--------
LOW NITRILE W	Mil-P-46002	2-year	Vapor	--------	--------
LOW NITRILE X	Neat	3-year	Submerged	--------	--------
LOW NITRILE Y	0.3 %	3-year	Submerged	--------	--------
LOW NITRILE Z	0.5%	3-year	Submerged	--------	--------
LOW NITRILE AA	0.7%	3-year	Submerged	--------	--------
LOW NITRILE AB	Mil-P-46002	3-year	Submerged	--------	--------
LOW NITRILE AC	Neat	3-year	Vapor	--------	--------
LOW NITRILE AD	0.3 %	3-year	Vapor	--------	--------
LOW NITRILE AE	0.5%	3-year	Vapor	--------	--------
LOW NITRILE AF	0.7%	3-year	Vapor	--------	--------
LOW NITRILE AG	Mil-P-46002	3-year	Vapor	--------	--------

VITON

VITON A	Air	1-Year		--------	--------
VITON B	Air	2-year		--------	--------
VITON C	Air	3-Year		--------	--------
VITON D	Neat	1-year	Submerged	--------	--------
VITON E	0.3 %	1-year	Submerged	--------	--------
VITON F	0.5%	1-year	Submerged	--------	--------
VITON G	0.7%	1-year	Submerged	--------	--------
VITON H	Mil-P-46002	1-year	Submerged	--------	--------
VITON I	Neat	1-year	Vapor	--------	--------
VITON J	0.3 %	1-year	Vapor	--------	--------
VITON K	0.5%	1-year	Vapor	--------	--------
VITON L	0.7%	1-year	Vapor	--------	--------
VITON M	Mil-P-46002	1-year	Vapor	--------	--------
VITON N	Neat	2-year	Submerged	--------	--------
VITON O	0.3 %	2-year	Submerged	--------	--------
VITON P	0.5%	2-year	Submerged	--------	--------
VITON Q	0.7%	2-year	Submerged	--------	--------
VITON R	Mil-P-46002	2-year	Submerged	--------	--------
VITON S	Neat	2-year	Vapor	--------	--------
VITON T	0.3 %	2-year	Vapor	--------	--------
VITON U	0.5%	2-year	Vapor	--------	--------
VITON V	0.7%	2-year	Vapor	--------	--------
VITON W	Mil-P-46002	2-year	Vapor	--------	--------
VITON X	Neat	3-year	Submerged	--------	--------
VITON Y	0.3 %	3-year	Submerged	--------	--------
VITON Z	0.5%	3-year	Submerged	--------	--------
VITON AA	0.7%	3-year	Submerged	--------	--------
VITON AB	Mil-P-46002	3-year	Submerged	--------	--------
VITON AC	Neat	3-year	Vapor	--------	--------
VITON AD	0.3 %	3-year	Vapor	--------	--------
VITON AE	0.5%	3-year	Vapor	--------	--------
VITON AF	0.7%	3-year	Vapor	--------	--------
VITON AG	Mil-P-46002	3-year	Vapor	--------	--------

FLOROSILICONE

FLORO SIL A	Air	1-Year		--------	--------
FLORO SIL B	Air	2-year		--------	--------
FLORO SIL C	Air	3-Year		--------	--------
FLORO SIL D	Neat	1-year	Submerged	--------	--------
FLORO SIL E	0.3 %	1-year	Submerged	--------	--------
FLORO SIL F	0.5%	1-year	Submerged	--------	--------
FLORO SIL G	0.7%	1-year	Submerged	--------	--------
FLORO SIL H	Mil-P-46002	1-year	Submerged	--------	--------
FLORO SIL I	Neat	1-year	Vapor	--------	--------
FLORO SIL J	0.3 %	1-year	Vapor	--------	--------
FLORO SIL K	0.5%	1-year	Vapor	--------	--------
FLORO SIL L	0.7%	1-year	Vapor	--------	--------
FLORO SIL M	Mil-P-46002	1-year	Vapor	--------	--------
FLORO SIL N	Neat	2-year	Submerged	--------	--------
FLORO SIL O	0.3 %	2-year	Submerged	--------	--------
FLORO SIL P	0.5%	2-year	Submerged	--------	--------
FLORO SIL Q	0.7%	2-year	Submerged	--------	--------
FLORO SIL R	Mil-P-46002	2-year	Submerged	--------	--------
FLORO SIL S	Neat	2-year	Vapor	--------	--------
FLORO SIL T	0.3 %	2-year	Vapor	--------	--------
FLORO SIL U	0.5%	2-year	Vapor	--------	--------
FLORO SIL V	0.7%	2-year	Vapor	--------	--------
FLORO SIL W	Mil-P-46002	2-year	Vapor	--------	--------
FLORO SIL X	Neat	3-year	Submerged	--------	--------
FLORO SIL Y	0.3 %	3-year	Submerged	--------	--------
FLORO SIL Z	0.5%	3-year	Submerged	--------	--------
FLORO SIL AA	0.7%	3-year	Submerged	--------	--------
FLORO SIL AB	Mil-P-46002	3-year	Submerged	--------	--------
FLORO SIL AC	Neat	3-year	Vapor	--------	--------
FLORO SIL AD	0.3 %	3-year	Vapor	--------	--------
FLUOROSILICONE AE	0.5%	3-year	Vapor	--------	--------
FLUOROSILICONE AF	0.7%	3-year	Vapor	--------	--------
FLUOROSILICONE AG	Mil-P-46002	3-year	Vapor	--------	--------

TEFLON

TEFLON A	Air	1-Year		--------	--------
TEFLON B	Air	2-year		--------	--------
TEFLON C	Air	3-Year		--------	--------
TEFLON D	Neat	1-year	Submerged	--------	--------
TEFLON E	0.3 %	1-year	Submerged	--------	--------
TEFLON F	0.5%	1-year	Submerged	--------	--------
TEFLON G	0.7%	1-year	Submerged	--------	--------
TEFLON H	Mil-P-46002	1-year	Submerged	--------	--------
TEFLON I	Neat	1-year	Vapor	--------	--------
TEFLON J	0.3 %	1-year	Vapor	--------	--------
TEFLON K	0.5%	1-year	Vapor	--------	--------
TEFLON L	0.7%	1-year	Vapor	--------	--------
TEFLON M	Mil-P-46002	1-year	Vapor	--------	--------
TEFLON N	Neat	2-year	Submerged	--------	--------
TEFLON O	0.3 %	2-year	Submerged	--------	--------
TEFLON P	0.5%	2-year	Submerged	--------	--------
TEFLON Q	0.7%	2-year	Submerged	--------	--------
TEFLON R	Mil-P-46002	2-year	Submerged	--------	--------
TEFLON S	Neat	2-year	Vapor	--------	--------
TEFLON T	0.3 %	2-year	Vapor	--------	--------
TEFLON U	0.5%	2-year	Vapor	--------	--------
TEFLON V	0.7%	2-year	Vapor	--------	--------
TEFLON W	Mil-P-46002	2-year	Vapor	--------	--------
TEFLON X	Neat	3-year	Submerged	--------	--------
TEFLON Y	0.3 %	3-year	Submerged	--------	--------
TEFLON Z	0.5%	3-year	Submerged	--------	--------
TEFLON AA	0.7%	3-year	Submerged	--------	--------
TEFLON AB	Mil-P-46002	3-year	Submerged	--------	--------
TEFLON AC	Neat	3-year	Vapor	--------	--------
TEFLON AD	0.3 %	3-year	Vapor	--------	--------
TEFLON AE	0.5%	3-year	Vapor	--------	--------
TEFLON AF	0.7%	3-year	Vapor	--------	--------
TEFLON AG	Mil-P-46002	3-year	Vapor	--------	--------

APPENDIX F

Fuel Filter Dimensions

Fuel Filter Dimensions - 1

AL-15437 Cotton Sock — Initial Measurements

Years		Height, in.	Diameter, in.
One	A-1	8.5	3.1
	A-2	8.5	3.1
Two	A-3	8.5	3.1
	A-4	8.5	3.1
Three	A-5	8.5	3.1
	A-6	8.5	3.2

AL-15437 Cotton Sock — Final Test Measurements

Years		Height, in.	Diameter, in.
One	A-1	8.5	3.3
	A-2	8.5	3.3
Two	A-3	8.5	3.125
	A-4	8.5	3.125
Three	A-5	8.25	3.125
	A-6	8.5	3.125

AL-15437 Pleated Paper — Initial Measurements

Years		Height, in.	Diameter, in.
One	B-1	7.9	2.8
	B-2	7.9	2.8
Two	B-3	7.9	2.8
	B-4	7.9	2.8
Three	B-5	7.9	2.8
	B-6	7.9	2.8

AL-15437 Pleated Paper — Final Test Measurements

Years		Height, in.	Diameter, in.
One	B-1	7.9	2.8
	B-2	7.9	2.8
Two	B-3	7.875	3.0
	B-4	7.875	3.0
Three	B-5	8.0	3.0
	B-6	8.0	3.0

AL-15344 Cotton Sock — Initial Measurements

Years		Height, in.	Diameter, in.
One	A-11	8.5	3.2
	A-12	8.5	3.2
Two	A-13	8.5	3.1
	A-14	8.5	3.1
Three	A-15	8.5	3.2
	A-16	8.5	3.1

AL-15344 Cotton Sock — Final Test Measurements

Years		Height, in.	Diameter, in.
One	A-11	8.5	3.3
	A-12	8.5	3.3
Two	A-13	8.5	3.125
	A-14	8.5	3.125
Three	A-15	8.5	3.0
	A-16	8.5	3.0

AL-15344 Pleated Paper — Initial Measurements

Years		Height, in.	Diameter, in.
One	B-11	7.9	2.8
	B-12	7.9	2.8
Two	B-13	7.9	2.8
	B-14	7.9	2.8
Three	B-15	7.9	2.8
	B-16	7.9	2.8

AL-15344 Pleated Paper — Final Test Measurements

Years		Height, in.	Diameter, in.
One	B-11	7.9	2.8
	B-12	7.9	2.8
Two	B-13	7.875	3.0
	B-14	7.875	3.0
Three	B-15	8.0	3.0
	B-16	8.0	3.0

AL-15437 = PEO-10 + 0.5 wt% VCI-B.
AL-15344 = PEO-10.

Fuel Filter Dimensions - 2

AL-15437 Phenolic Resin Initial Measurements			
Years		Height, in.	Diameter, in.
One	C-1	6.9	3.0
	C-2	6.9	3.0
Two	C-3	6.9	3.0
	C-4	6.9	3.0
Three	C-5	6.9	3.0
	C-6	6.9	3.0

AL-15437 Phenolic Resin Final Test Measurements			
Years		Height, in.	Diameter, in.
One	C-1	6.9	3.0
	C-2	6.9	3.0
Two	C-3	7.0	3.1
	C-4	7.0	3.1
Three	C-5	7.0	3.1
	C-6	7.0	3.1

AL-15437 Wound Cotton String Initial Measurements			
Years		Height, in.	Diameter, in.
One	D-1	8.0	2.4
	D-2	8.0	2.4
Two	D-3	8.0	2.4
	D-4	8.0	2.4
Three	D-5	8.0	2.4
	D-6	8.0	2.4

AL-15437 Wound Cotton String Final Test Measurements			
Years		Height, in.	Diameter, in.
One	D-1	8.0	2.4
	D-2	8.0	2.4
Two	D-3	7.75	2.5
	D-4	7.75	2.5
Three	D-5	7.875	2.375
	D-6	7.875	2.375

AL-15344 Phenolic Resin Initial Measurements			
Years		Height, in.	Diameter, in.
One	C-11	6.9	3.0
	C-12	6.9	3.0
Two	C-13	6.9	3.0
	C-14	6.9	3.0
Three	C-15	6.9	3.0
	C-16	6.9	3.0

AL-15344 Phenolic Resin Final Test Measurements			
Years		Height, in.	Diameter, in.
One	C-11	6.9	3.0
	C-12	6.9	3.0
Two	C-13	7.0	3.1
	C-14	7.0	3.1
Three	C-15	7.0	3.1
	C-16	7.0	3.1

AL-15344 Wound Cotton String Initial Measurements			
Years		Height, in.	Diameter, in.
One	D-11	8.0	2.4
	D-12	8.0	2.4
Two	D-13	8.0	2.4
	D-14	8.0	2.4
Three	D-15	8.0	2.4
	D-16	8.0	2.4

AL-15344 Wound Cotton String Final Test Measurements			
Years		Height, in.	Diameter, in.
One	D-11	8.0	2.4
	D-12	8.0	2.4
Two	D-13	7.75	2.5
	D-14	7.75	2.5
Three	D-15	7.875	2.375
	D-16	7.875	2.5

AL-15437 = PEO-10 + 0.5 wt% VCI-B.
AL-15344 = PEO-10.